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Review of Textile Research and Development During 1951*

Edited by

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I. Summary

This paper is a review of the literature published during 1951 in the field of textile science and technology. The material reviewed in this paper includes publications in the fields of pure and applied research, as well as in development, and has been selected from the scientific and technical journals published in the United States and abroad and from certain standard abstract journals. The format of the review has been controlled largely by the scope and character of the papers which have been published in the fields of research and development during the past year.

The bibliography has been arranged to conform with the main divisions and subclassifications of the review. The individual papers cited are numbered consecutively in the bibliography and are referred to in brackets in the body of the text; the papers in each of the principal sections under the main headings of "Research" and "Development" are arranged in alphabetical order by first author.

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II. Review Papers of General Interest

The second volume of the *Review of Textile Progress* produced by The Textile Institute and the Society of Dyers and Colourists has been announced [9]. Textile research and development for the year 1950 has also been reviewed by members of the staff of Textile Research Institute [22], and an excellent summary of textile research achievements in 1951 has been made by Goldberg [7]. The current program of Textile Research Institute for the fiscal year 1950–51 has been outlined in the *Annual Report* of its director [3]. Rowe [21] has presented a general discussion of recent textile trends. The extension of research techniques to new fields of application in the textile industry, particularly to the improvement of mill processing operations and to the evaluation of fabric properties, has been discussed by Hopkins [14]. Ashcroft [5] and Brooks [6] have considered the impact of consumer requirements on research planning. Recent advances in textile processing, equipment design, and production methods have been reviewed [1, 2, 4].

Parsons and Stearns [19] have recently published a book dealing with the production and properties of

cotton, wool, and man-made fibers, as well as with the characteristics and production of various kinds of yarns made from these fiber types. A group of papers dealing with the solid state of high-polymeric substances has occupied a recent issue of *Kolloid-Zeitschrift* [18]. Ridge has discussed the impact of the new textile materials on both the manufacturer and consumer [20]. Harris has discussed the industry needs in terms of particular types of new synthetic fibers [11, 12]. The economic aspects of rayon staple have been discussed in a review article by Sweers [23]; Levison [16] has outlined the research program of the A.K.U. It has been stated [8] that part of the increased demand for additional textile materials for defense requirements will be supplied by new and expanded plants for synthetic fiber production; figures indicate, however, that to replace 10% of the world's output of wool by synthetic materials would require a capital outlay nearly equal to the entire investment of the United States in the chemical industry [15].

Traill [24] has given an excellent review of the availability and properties of both natural and synthetic textile fibers in a discussion concerning the problems of clothing an expanding population. Herrington [13] has discussed clothing from a biophysical point of view, dealing with hygroscopic fiber properties, measurements of clothing insulation, and radiation barriers. Some of the problems in the translation of fiber properties into yarn and fabric properties have been presented by Hamburger [10].

Lloyd [17] has given a critical review of textile education in Great Britain. Closely associated with this subject, Withers has discussed in the 1951 Mather Lecture the production and utilization of textile information [25].

III. Research

A. Chemistry of Cellulose and Starch—Richard Steele

1. Cellulose.—Kenyon [83] has reviewed the history of the Cellulose Division of the American Chemical Society and the progress in cellulose chemistry since its formation.

(*a*) Structure of Cellulose: Nickerson [108] has summarized the available information on the relative accessibility or crystallinity of cellulose and discussed some of the implications of this data. Timell has included a critical review of this problem in a thesis [139], which summarizes his series of papers on cellulose reactions, previously discussed in these "Reviews" ([170–174] in the 1949 "Review" and [111, 112] in the 1950 "Review"). Centola [39] has emphasized the importance which the mesomorphous regions, intermediate between crystalline and amorphous forms, have in determining the reactability of cellulose. Tarkow [137] has discussed the measurement of accessibility by the use of formylation, as proposed by Nickerson [107], and Glegg [66] has reported on the use of chromium trioxide oxidation for this purpose. Foster and Wardrop [55] have compared the crystallinity of wood cellulose and cotton as determined by the acid hydrolysis technique. The heat of crystallization of cellulose has been measured by Calvet and Hermans [38], who have shown that this information makes it possible to estimate the crystallinity of a cellulose sample from simple calorimetric measurements if suitable standards of known crystallinity are available. Forziati and Rowen [53] have observed differences in the infrared spectra of amorphous, native, and mercerized celluloses, which may prove useful in evaluating changes in the crystal structure of cellulose. The most striking differences in the spectra were in the 7 μ to 8 μ and 9 μ to 10 μ regions. Infrared studies in the 3 μ region have been made by Brown, Holliday, and Trotter [36] on native and regenerated cellulose and a number of cellulose derivatives. They have shown that the shape and frequency of the OH stretching absorption can give considerable information about hydrogen-bonding conditions and the uniformity of substitution along the cellulose chains.

Beall and Jörgensen [32] have developed a new treatment for handling the chain length frequency distributions in degraded cellulose, which indicates that hydrolytic cleavage occurs randomly throughout the length of the molecule. There has been some discussion of the significance of some results of the heterogeneous hydrolysis of methyl cellulose [121] and the nature of the methoxyl groups introduced during the methanolysis of cellulose [110, 111, 122]. Gibbons [62, 63] has studied the homogeneous acid hydrolysis of methyl cellulose and observed that the hydrolytic attack appears to be random along the chains.

Jayme [76] has discovered that with certain precautions cobalt-ethylenediamine solutions can be prepared which will dissolve cellulose. The effect of ammonia and alcohol on the rotation of cellulose in

cuprammonium solutions has been investigated by Arkhipov and Kharitonova [30], who have also studied such cellulose solutions potentiometrically [31]. Adams, Karon, and Reeves [26] have measured the electrophoretic migration of cellulose in cupriethylenediamine solution. Centola [40] has recently summarized some of his work and that of others on the solubility of cellulose. Rauch [119] has considered the practical problems presented by the fact that most cellulose solvents leave small particles of the original material undissolved. König [86] has studied the conditions under which cellulose may be dissolved in sulfuric acid to produce solutions suitable for use in preparing fibers and films.

Gellendien [61] has reviewed some of the information available on animal cellulose and suggested that further work on its structure would be desirable. Meyer, Huber, and Kellenberger [100] have observed flat fibrils in electron micrographs of cellulose from tunicin, and Forziati and Rowen [53] have compared the infrared spectrum of valonia cell wall with plant celluloses. The formation of cellulose by *Acetobacter acetigenum* has been studied by Kaushal and Walker [82].

(*b*) Cellulose Reactions and Derivatives: Nevell [105] has investigated the oxidation of cotton cellulose with nitrogen dioxide, with particular attention to side reactions which produce reducing groups and carboxy groups at other than the sixth carbon atom of the glucose residue. Nevell [106] has also made a qualitative x-ray study of this reaction. Oxidation of glucose with nitrogen dioxide produces saccharic acid in up to 50% yield, according to Degering and Berntsen [49]. The preparation and properties of nitrates of nitrogen dioxide-oxidized cellulose have been studied by Treĭvas, Shorygina, and Rogovin [144]. The nitrated products were compared with natural polyuronic acids. Yashunskaya and coworkers [147] prepared some dicarboxycelluloses by oxidation of dialdehyde-cellulose and have studied their acetylation. Rowen, Forziati, and Reeves [123] have discovered that dialdehyde-cellulose, prepared by periodate oxidation, does not show any evidence of free aldehyde groups in its infrared spectrum, and they suggest that these groups are probably hydrated. Head [69] also discussed some structures for this material which would fit this and other evidence. Patel [113] has used optical methods to investigate the oxidation of cellulose with periodate, chromic acid, and hypobromite. His observations are in good agreement with conclusions arrived at from x-ray and other data about these reactions. Davidson and Standing [47] have shown that acidic oxycelluloses are inherently unstable when their carboxyl groups are in the free-acid form because of a slow autohydrolysis. The alkali stability of oxidized, hydrolyzed, and methanolyzed celluloses has been studied by Meller [99], and Pinte [116] has also discussed some physical-chemical properties of degraded celluloses. An extensive study has been made by Head [69] of the action of diazomethane on cotton and on oxycelluloses prepared with periodate and nitrogen dioxide. Reeves, who originally noted the stabilizing effect which diazomethane has on periodate oxycellulose, has also found [120] that this reagent reduces the susceptibility to alkali damage of cotton oxidized with neutral hypochlorite. Studies of some of the properties of rayon and cotton after oxidation with hypochlorite have been reported [101, 117, 134]. Samuelson and Hartler [126] have compared the effects of chlorine dioxide and chlorite bleaching on some chemical properties of cellulose. The oxidation of cellulose in cupriethylenediamine solutions has been studied by Cyrot [46].

Lauer has investigated the reaction of sodium hydroxide with cellulose [89] and has measured the heat evolved in this process [90]. The sodium hydroxide-cellulose reaction has been used by Calkin [37] to determine apparent ionization constants for cellulose. Samuelson, Gärtner, and Johansson [125] have measured the ion exchange between potassium cellulose and sodium ions, and between radioactive sodium cellulose and inactive sodium ions. The presence of crystalline regions afforded no detectable hindrance to the exchange reaction. Champetier and Ashar [41] have found that although under certain conditions potassium and sodium hydroxides are absorbed in simple stoichiometric ratios, lithium hydroxide does not show any such relationship. An apparatus and a method for determining the alkali absorptivity of cellulose have been described by Nagrodskiĭ [104]. The absorption by cellulose of zinc-, nickel-, cobalt-, and copper-hydroxides from alkaline solutions has been measured by Pakshver, Arkhipov, and Geller [112]. The effect of repeatedly boiling cotton and regenerated cellulose in aqueous alkali solutions, such as those used for laundering, has been reported by Schaeffer [128]. He has also studied [127] the effect of oxygen under these conditions.

By careful selection of conditions and reagents, Malm and coworkers [96] have been able to prepare the higher homologs of cellulose acetate so that esterification is essentially complete and the esters all have the same D.P. Data on the physical properties of such a homologous series from cellulose acetate to cellulose palmitate have been reported [97]. Howlett and Urquhart [74] have discussed the relationship between the structure of cellulose acetates and their solubility, and the effect of fairly small inhomogeneities in acetyl content on the swelling and solubility of cellulose acetate was shown by the work of Alexander and Rabinovitch [27]. Kraus [87] has compared the rates of solution of 71 solvents for cellulose ethers and esters, using acetone as a standard for comparison. The failure of cellulose acetate solutions to give linear relations between their optical and other properties has been attributed by Signer and coworkers [135] to the presence of some coarser, easily oriented particles along with the molecularly dispersed material. Choudhury and Palit [43] have studied the preparation of secondary cellulose acetate from short-staple Indian cotton. Bischoff and Desreux [33] have used a turbidimetric titration technique for studying cellulose acetate solutions, and Herrick [73] has investigated the periodate oxidation of cellulose acetates of a low degree of substitution. The ultraviolet absorption spectra of fractionated cellulose acetates were determined by von Keussler, Mecke, and Sippel [84]. Borgin [34] has suggested a new method for determining the reactivity of cellulose to acetylation; it is based on the measurement of the change in conductance of an acetylating mixture of acetic anhydride and methylene chloride as the acetylation of a cellulose sample proceeds. Garetto and Casarico [57] have given a technique for combined acid determination in mixed esters of cellulose.

By the isotope enrichment technique, Klein and Mentser [85] have confirmed that nitration of cellulose occurs through the electrophilic attack on the hydroxyl oxygen by the NO_2^+ ion with subsequent proton elimination. Rånby and Sihtola [118] have studied the high-temperature acid hydrolysis of nitrocellulose and found that the reaction appeared to be heterogeneous. The hydrolytic and thermal degradation of cellulose nitrates has been discussed by von Gizycki [64, 65]. Lipatov and Meerson [93] have found that the heat of solution of nitrocellulose films prepared from concentrated solutions is greater than that of films cast from dilute solutions because the latter entrap more solvent. The structure of nitrocellulose membranes has been studied by Peters [114, 115]. The viscosity [81] and gelation [78] of cellulose sulfates have been investigated by Kagawa and coworkers, and Touey [143] has described some of the properties of this material which may make it useful for such purposes as building detergents or warp sizing. Marvel and Bluestein [98] have prepared some phosphorus-containing cellulose derivatives by reacting cellulose acetate-chloroacetate with triethyl phosphite.

Two papers [42, 88] have appeared describing investigations of the course of the xanthation reaction and the distribution of xanthate groups along the cellulose chains. Tait and coworkers [136] have studied the intrinsic viscosity of cellulose xanthate solutions as a function of electrolyte concentration of the solvent. They have accounted for the change in viscosity by showing, with the help of light-scattering measurements, that in pure water the cellulose xanthate molecule should approach the rigid rod configuration, while in caustic, a more random, coiled configuration occurs. Herrent, Ludé, and Mouraux [72] have measured the dependence of the viscosity of viscose on the rate of shear as a function of such factors as cellulose concentration, D.P., etc. Bréguet and Viatte [35] and Mitchell [102] have investigated the degradation which occurs during the ripening of alkali cellulose. Mitchell emphasized that the rate of degradation, which is quite characteristic for a given cellulose, is as important as its original D.P. in determining the viscosity of viscose prepared from it. Gärtner and Samuelson [58–60] have continued their investigation of the emulsion xanthation of cellulose. The emulsion technique is also discussed in a paper on xanthation by Lauer and Pauer [91], who have also investigated [92] the xanthation of degraded cellulose. The composition of viscose has been studied by methods involving potentiometric titration [70] and ultraviolet spectrophotometry [129]. An explanation [79] in terms of gelation phenomena has been suggested for the Hottenroth test for viscose ripening. Wannow [145] has discussed the factors which influence the filterability of viscose, and Herrent, Ludé, and Jnoff [71] have made some progress in attempting to establish a practical way of expressing this property of viscose. Tomberg [141, 142] has made some observations on the coagulation of viscose, including the effect of ultrasonic irradiation.

A new method for studying the early stages of cellulose reactions has been proposed by Timell and Purves [140]. Samples taken at suitable times are nitrated without degradation and then fractionated. MacGregor has surveyed [94] the reaction of acrylonitrile with high molecular weight hydroxy compounds and outlined [95] the conditions suitable for the reaction between the nitrile and viscose to produce water-soluble yarns. The chemistry of the reaction and the usefulness of such yarns are discussed. The thermal decomposition of cellulose and its amide has been studied by Costa and Costa [45], and Scherer and Iacoviello [130] have investigated the effect of degree of substitution on the fractionation of ethyl cellulose. Senju has reported on the preparation of hydroxyethylcellulose by the action of ethylene oxide on alkali cellulose [132], a method for determining the degree of substitution of this material [131], and a study of its allylation [133]. Nikitin and Klenkova [109] have studied the effect of a low degree of etherification on the chemical properties of cellulose. Coenen [44] has presented a review of the production and properties of cellulose urethans. Kagawa and Katsuura [80] have measured the dissociation of carboxymethylcellulose at different pH's and electrolyte concentrations. The effects of cross-linking cotton cellulose with formaldehyde have been investigated by Goldthwait [67], and the practical value of this reaction has been discussed by Hall [68]. Dean [48] has presented some evidence that urea-formaldehyde resins may form covalent cross links when applied to cellulose, and Eckert and coworkers [51] have reported on the cross-linking of cellulose through urethan formation using dicarboxylic acid halogen amides and their salts.

(*c*) Analysis of Cellulose and Its Derivatives: The application of the Kiliani reaction as a quantitative end-group measure for polysaccharides, such as cellulose, has been examined by several workers [56, 75, 148]. Isbell [75] has suggested the use of radioactive cyanide for this purpose. The determination of α-cellulose and its significance to the viscose industry have been reviewed by Jentgen [77], Weller [146], and Doering [50]. A number of methods for estimating carboxylic acid groups in cellulose have been suggested. Nabar and Padmanabhan [103] have determined carboxyl groups in oxycellulose by allowing them to react with iodate-iodide and titrating the iodine released. Forziati, Rowen, and Plyler [54] have proposed a method which makes use of the absorption by carboxyl groups in the infrared region of the spectrum. Farrar, Neale, and Williamson [52] have determined cellulosic carboxyl groups gravimetrically by soaking the sample in uranium acetate solution, ashing it after washing, and weighing the ash as uranium oxide. The method presented by Ant-Wuorinen [28, 29] measures the hydrogen ions freed when the cellulose is allowed to equilibrate in dilute sodium chloride solutions.

Techniques for applying the anthrone method to the determination of carboxymethylcellulose [1086] and methylcellulose [124] have been worked out, and Thinius [138] has described a number of solubility tests for identifying various high polymers.

2. Starch.—

(*a*) Structure: Wolfrom and his coworkers have presented further evidence that chain branching occurs at the 6-position in amylopectin and glycogen by isolating crystalline derivatives of isomaltose [213, 214] and panose [205] as degradation products of these materials. Examination of hydrolysates from periodate-oxidized amylopectin and glycogen by Gibbons and Boissonnas [163] has also indicated that branching occurs exclusively at this 6-position. Hobson, Pirt, Whelan, and Peat [168] have modified and improved the thymol method for separating the amylose and amylopectin of potato starch, and Ulmann [206, 207] has separated the components of this starch chromatographically. The D.P. of corn and tapioca amylopectin acetates has been determined osmometrically by Kerr, Cleveland, and Katzbeck [178]. Studies of subfractions of these amylopectins by Potter and Hassid [194] indicated that all the amylopectin molecules of a particular starch possess the same average number of glucose residues per terminal glucose unit. Goodison and Higginbotham [164] have developed a general method for the fractionation of amyloses by fractional solution, and studies of amylose fractions by Higginbotham [167] and Potter and Hassid [193] have suggested that amyloses from different starches may be slightly branched in varying degrees or may contain branched components which are not removed in the usual separation techniques. The amylose contents of different varieties of sweet potatoes [158] and the preparation and properties of amylose films [210] have been reported.

Kreger [181] has obtained x-ray diffraction patterns from single starch grains and interpreted them

in terms of the configuration and packing of the chain molecules. The action of ultrasonic waves on starch has been studied by Sutra [204], and Bechtel [154] has found that the usual dispersive methods for starch leave particles which can be observed with the phase microscope. Techniques for measuring the fat content [183], pH [190], and hydration [215] have been reported, as well as a method for determining starch itself by acid hydrolysis [192]. Samec [198] has reviewed some of his contributions to starch research.

(*b*) Enzymatic Synthesis and Hydrolysis: The enzymatic synthesis of starch from glucose-l-phosphate seems to occur through the action of phosphorylase to produce amylose, which is converted by *Q*-enzyme into amylopectin, as proposed by Hobson, Whelan, and Peat [170] and confirmed by other workers [191]. Barker, Bourne, Peat, and Wilkinson [152] have shown that mixtures of the phosphorylase and *Q*-enzyme of the potato can produce starchlike products. The relative proportions of the two enzymes determine the properties of the product [153]. This mechanism of starch synthesis by potato enzymes is apparently duplicated by the enzyme systems of the broad bean and wrinkled pea [169]. The priming action of short-chain maltose polymers ($n = 3$ to 6) in the synthesis of starch has been studied by Bailey, Whelan, and Peat [151]. Some doubt has been cast on the existence of an "isophosphorylase" in the potato [150, 191]. Stacey [203] has reviewed biological polymerization with reference to polysaccharide synthesis, while Hough and Jones [173] have outlined what is known of the biosynthesis of the simple sugars.

Meyer [185] and Kerr and Gehman [179] have comprehensively reviewed the action of amylases on starch, and Meyer and Gonon [186–188] have reported the action of crystalline α-amylase on starch, amylose, and amylopectin. Dimler, Bachmann, and Davis [157] have also investigated the hydrolysis of amylose by α-amylase. A study of the action of crystalline β-amylase on crystalline amylose has led Kerr and Cleveland [176] to conclude that the "single-chain" theory of β-amylase action is strongly favored. Various aspects of the action of amylases on starch have been investigated by Specht [202], Ulmann [208], Schwimmer [199], and Samec [197]. The oxidative inactivation of β-amylase has been found by Englard, Sorof, and Singer [160] to be intramolecular. A new strain of bacteria which produces a hexasaccharide different from Schardinger dextrin has been described by Akiya and Watanabe [149]. Katz and Hassid [175] have studied the effect of the addition of inorganic arsenate on the reaction of starch with phosphorylase, and the action of amylo-glucosidase on starch has been investigated by Kerr, Cleveland, and Katzbeck [177]. The α-amylase of *Aspergillus oryzae* has been crystallized [161], and an enzyme which catalyzes the scission of branch links in amylopectin has been isolated and studied [156, 171, 184].

(*c*) Starch Derivatives: Wolff, Olds, and Hilbert have worked out procedures for preparing a number of starch esters [211] and have surveyed their properties for possible industrial applications [212]. Benzoyl derivatives of starch have been discussed by Ciusa and Adamo [155], inorganic acid esters by Graefe [166], and the nitrate by Vollmert [209]. The preparation of the methyl and ethyl esters of starch, amylose, and amylopectin in liquid ammonia has been investigated by Hodge, Karjala, and Hilbert [172]. Studies of the oxidation of starch formate with periodate [189] and of amylose with hypochlorite [174] have been reported. Yovanovitch [216] has found that starch forms addition compounds with sodium hydroxide, and the applications of starch and its derivatives in the textile and paper industries have been outlined by Snijder [201].

(*d*) Miscellaneous: Fuller [162] has presented a brief review on methods of following the depolymerization of starch, and papers have appeared on its degradation by acid [159, 182], by heat [165], and by gamma rays [180]. Reiff [195] has contrasted the ease of hydrolysis of starch by acids or enzymes with the relative resistance of cellulose. The use of paper chromatography in studying starch hydrolysis is described by Rüggeberg [196]. Sink and Worth [200] have presented a modification of the perchloric acid method for determining starch and have illustrated how it may be used in studying enzymatic desizing.

B. Structure and Properties of Cellulose Fibers—Helmut Wakeham

1. Reviews.—For reviews of the development of native and regenerated cellulose fibers and of our present knowledge of their structure, the reader is referred to references [217–224].

2. Bast and Hard Cellulose Fibers.—The technological importance of these fibers has been surveyed

by various authors as follows: general [257], flax [247, 253], jute [235, 251], kenaf [236, 238, 241], ramie [237, 240, 258], and sisal waste [254, 255].

Considerable work has been done on the problems of decortication and degumming processes which are necessary prior to manufacturing these fibers into yarns or fabrics. Asai and coworkers have reported microbiological studies on the degumming of Manila hemp [226], ramie [227, 228], and mulberry fibers [229]. Bychkovskaya [232] has identified organisms which break down organic acids in acidic retting liquors. A chlorine dioxide solution for removing lignin from jute fiber has been described [252]. The differences in the disintegration of various fiber plants have been investigated by Tobler [256].

Additional structure studies on these fibers have been reported. Sarkar [249] has concluded that jute either contains no cellulosan or has a cellulosan which is free from xylan. Adam [225] has investigated the low-angle x-ray scattering for ramie and jute. He observed a pattern which he attributed to the close packing of the crystallites in the fiber, and then used this pattern to follow the effect of lignin removal upon the intermicellar swelling of the fibers in water. Mukherjee and Woods [245] have followed the transition from water cellulose to cellulose II in ramie, jute, and sisal by means of x-ray measurements. In a microscopic study, Roelofsen [246] has compared the spiral structures of flax, hemp, and ramie.

Two methods for measuring the interfiber friction of jute fibers as related to spinning process have been described [230, 233]. Sen [250] has set up a torsion pendulum method for comparing the twist-resistance of different jute fibers. The importance of friction and twist-resistance as factors in the determination of optimum and minimum twist for jute yarns has been discussed by Chakrabarti [234] and Mukherjee [244].

Kaswell and Platt [239] have reported on a study of the mechanical properties of sansevieria, henequen, sisal, and abaca which are significant in terms of their performance as cordage materials. They have shown that the elongation properties of a cordage fiber are of equal importance with strength properties in determining the performance of cordage in shock loading and in repeated stress application. Potential performance of a fiber is best defined by its energy absorption characteristics. A fairly complete survey of the mechanical behavior of these fibers is given in this paper.

Macmillan and Sen Gupta have reported work on the bleaching [243] and partial acetylation [242] of jute fibers. The effects of common bleaching agents on the strength, degradation, and chemical composition of jute have been described. It was shown that partial acetylation ties up the hydroxyl groups in the hemicellulose of the fiber and prevents the discoloration of jute by ultraviolet light.

Studies on the assessment of fungal damage [231] and liability to spontaneous combustion [248] have also been made.

3. Cotton.—A complete chemical analysis of six commercial raw cottons has been made at the Southern Regional Research Laboratory of the U. S. Department of Agriculture [279]. In addition to previously reported constituents, it was found from analysis of the ash of two cottons that the principal metal present is potassium.

The complicated interrelationships between the various forms of cellulose, cellulose hydrates, and alkali celluloses and their "crystal" structures remain to be clarified [267, 275–278, 303]. Only the native (cellulose I) and regenerated (cellulose II) forms are known with any certainty, although Sippel [294] has recently proposed another refinement of his boat-shaped model for the native cellulose chain. In a somewhat different approach to the problem, Tönnesen [298] has applied the x-ray diffraction methods used on liquids to obtain a radial distribution pattern for unoriented samples of regenerated cellulose; this work is still in progress.

The situation with regard to the determination of crystallinity seems to be improving [261, 268, 269]. It is generally recognized that physical methods for determination of crystallinity do not, in general, provide an estimate of "accessibility" as measured by chemical methods. Among the latter methods, one using formic acid esterification promises to be of value [107]. It seems reasonable to assume that mechanical properties might properly correlate better with "crystallinities" and that chemical reactivity would be related well with "accessibilities." Swelling cotton in such nonaqueous media as aliphatic amines causes a decrease in its crystallinity [293].

Interest in the electrical properties of cellulosic material continues. Papers on the piezoelectric properties of wood [260], the dielectric properties of wood pulps [301], and the electrokinetic potential of cotton [288] have appeared in the last year.

The arrangement or orientation of crystallites into "microfibrils" within the fiber has received a good deal of attention [272, 283, 289, 290, 296, 297]. The cellulose chains (and long crystallite axis) are parallel to the axis of the fibrils which are estimated from electron micrographs as being from 100 to 750 Å. in thickness. Frey-Wyssling [265, 266] seems to prefer a value of about 250 Å., which makes each microfibril have about 2000 cellulose chains in cross section. Chemical disintegration of cotton, ramie, and jute gives smaller "micellar particles" which are roughly 50 Å. thick, 150–200 Å. wide, and 500–2500 Å. long. In addition to the previously used polarized light and x-ray methods for defining the orientation of these structural units in the fiber, Meredith [280, 281] has suggested that the "convolution angle" may be used in place of the conventional x-ray angle to indicate the spiral orientation of cotton. He has also described an improved x-ray angle method.

A number of excellent studies of cotton fiber morphology has been made in recent months. It has been found that the primary wall of fully matured fibers can be isolated by means of a mechanical disintegration and flotation process [300]. Chemical analysis reveals that this wall contains only 50% cellulose, the remainder being mainly protein, wax, and pectic substances. Electron microscope examination of the primary wall [291, 300] shows a fibrillar network which fails to show the orientation found by means of the polarizing microscope for layers deeper in the fiber. This primary wall is largely removed when the cotton is subjected to alkaline scouring [273]. When the outer and secondary walls of the cotton fiber are digested by means of 72% sulfuric acid, the fiber lumen can be isolated [262]. These lumens appear to be tubular in shape and to have an unoriented, granular structure.

It is becoming more apparent that simple values of amorphous-crystalline ratios and average orientations are not sufficiently explicit to describe the mechanical behavior of native cellulose fibers. Morphological characteristics must also be taken into account in order to explain the large variations between individual fibers. For example, it has been shown that although structural reversals in the cotton fiber are points of weakness where the fiber prefers to break, these points are not the only locations of weakness [302]. Other morphological imperfections are also important in determining the strength of the cotton fiber [263, 282]. Various degrees of perfection between the recognizable crystallites and the poorly arranged amorphous regions appear to exist, and the stress distribution in a network of this type must be considered. Herrent and Ludé [270] have attempted to simplify this into a system composed of a primary network with rigidly bound crystallites and a secondary network in which the binding between bundles of macromolecules is more or less transitory. Some such description may be necessary to account for all the observable static and dynamic mechanical properties and the complicated changes which take place as a result of changing the moisture contents of the fibers [259, 284–287].

The degradation of cotton cellulose as the result of heating and mechanical action has been well established. Thermal degradation of tire cords in tires results in a decrease in degree of polymerization of the cellulose, strength, average modulus, and breaking toughness [264, 299]. Mechanical action in the beating stages of cotton processing also causes a decrease in degree of polymerization of the cotton in direct relation to the extent of treatment [304].

Improved methods have been described for the determination and definition of cotton fiber fineness and maturity [271, 274, 295], and for measuring various cottons in fibrous form for their suitability in making swelling-type, water-resistant fabrics [292].

4. Rayon.—One of the most interesting structural problems in the rayon field is the orientation and size of the crystallites present in the fiber as related to the stretching and tension imposed on the fiber both during spinning and in subsequent use. It has been recognized for some time that these crystallites in regenerated cellulose which are formed in the coagulating bath are generally smaller than the ones in native cellulose fibers and that upon stretching the fiber they become more oriented in the direction of stretching. Recent careful x-ray studies of various rayons lead to the suggestion that the crystallites may be considered to be more like platelets, which have been deformed in the orientation process, than like rods. There is, furthermore, evidence that the crystallite size distribution is changed when tension is applied to the system. The trend is, thus, toward the view that these fibers contain regions which range widely in size and crystallite perfection and that the distributions of size and order depend upon the method of fiber production and upon the extension imposed upon the fiber both during and after spinning [312, 314, 319–321, 323, 327, 330, 333, 341].

Additional attention has been given to the rayon fiber morphology revealed by the "peeling-off" acetylation method of Elöd [313, 329]. It has been shown by this method that there are very pronounced differences between various types of regenerated cellulose fibers. In viscose fibers the orientation of the crystalline regions generally decreases from outside inward [332]. With cuprammonium rayon the reverse is true. From the point of view of mechanical behavior it is believed that fibers of the latter type might be more desirable, and some success at producing such fibers by the viscose process has been reported [326]. Topochemically acetylated viscose fibers which have previously been produced experimentally are of this type.

Several studies on the effect of sodium hydroxide solutions on rayon fibers have been made. Hermans [315] has shown that with 18% concentration the x-ray determined crystallinity of rayon increases to 50%, whereas the same property for native celluloses decreases to the same value of 50%. At this condition, Bréguet and coworkers [306] found that the regenerated cellulose stretches a great deal more than the native cellulose. Thus, although the crystallinity of these two fibers in the caustic medium is the same, the distribution of the crystalline regions in the two cases would appear to be different. These differences have been suggested as a basis for characterizing regenerated celluloses [305, 331].

The importance of molecular weight of the cellulose in determining the properties of rayon fibers has been further emphasized in recent work. The molecular weight distribution has been shown to be related to the fatigue-resistance and dynamic properties of tire-cord viscose rayons [307]; the presence of low molecular weight material has been found to be particularly detrimental in this respect. For reasons such as this, attempts have been made to produce viscose rayons from solutions in which the cellulose has considerably higher D.P. (450–1000) than those commonly employed [338, 339]. Engelmann [309] has discussed the relationship between the molecular weight of cellulose acetates and the strength of fibers and films made from them. It is of interest to note in this connection that the application of ultrasonic radiation to the viscose solutions during ripening has been found useful in removing the bubbles but at the same time causes some degradation of the cellulose [336].

Horio and coworkers [316–318] have studied the viscoelastic properties of viscose monofils and acetate films by means of a vibrating reed technique. As a result of their considerations they have proposed a generalized mechanical behavior for high-polymer materials in the whole spectrum of loading frequencies.

Investigations have been reported on the effect of heat treatment [311, 328] and swelling treatment [310] on the mechanical behavior of rayon fibers. Studies have also been made on the friction, luster, durability, and knitting properties [308, 337, 340, 342, 343]. Further applications of the iodine absorption technique for evaluating crystallinity of rayon fibers have been reported [334, 335].

Experimental studies on the incorporation of acrylate resins [324] and vinyl polymers [322] into regenerated cellulose fibers have been made. Nitrated viscose fibers have also been described [325].

C. *Structure and Properties of Protein Fibers* —*Harris M. Burte*

1. Wool.—Trends in wool research have been discussed by Bray and Carter [377, 380] and by Hopkins [402]. Hirsbrunner [400] has contributed the first of a series of extensive review articles, and van Overbeke [436] has published a review on the structure and chemistry of wool.

(*a*) Growth: Knowledge about the keratinization of hair, nails, and the epidermis has been reviewed by Giroud and Leblond [391]. Keener and Percival [414] have studied the function of cobalt in the nutrition of sheep, and the effect of climate and nutrition on animal fibers has been discussed by Stoves [471]. Fraser [387] has presented evidence indicating that adjacent follicles on the skin of the sheep compete with each other for a limited amount of fiber substrate. Examination of longitudinal cuts through the human scalp has been used by Heilingötter [399] to study keratinization during the growth of hair. His results confirm Mercer's finding of five zones of keratinization between the papilla and shaft of the hair. Rees [454] has suggested that fibrous proteins are formed *in vivo* by a linear aggregation of small particles and has discussed mechanisms for such a directed aggregation. Sedimentation analysis of an extract of the prekeratinous layers of skin have been reported by Mercer and Olofsson [427]. They have described an asymmetric molecule which may play an important role in keratin synthesis.

(*b*) Protein Structure: The structure of keratin fibers has been reviewed by Alexander [344], Bam-

ford [361], Astbury [360], and Shimanouchi and Mizushima [464]. Elliott and Manogue [386] have pointed out that discussions of the structure or properties of wool should not neglect the polyphase nature of the fiber.

The surface structure of the wool fiber has continued to be the subject of much experimentation and discussion as well as of some controversy. The existence of the epicuticle is generally acknowledged. Similar membranes have been detected in electron micrographs of preparations from human skin and fingernails [419]. Zahn [479] has discussed published evidence indicating that the epicuticle of an animal fiber is not a continuous sheath. Alexander and Earland ([245] in 1950 "Review") had previously reported the existence of another membrane, situated between the cortex and the scales, called the "subcuticle," which has now been found [397] to give a β-type x-ray diffraction pattern. There has been considerable discussion of whether this pattern may be due to changes induced during dissolution of the fiber [426, 446] and whether the subcuticle may not consist merely of resistant cortical cells adhering to the epicuticle membrane [346, 393]. Mariner [424] has obtained a membrane, similar to that of Alexander, from which an epicuticle layer can be stripped.

In connection with the chemical resistivity of these membranes, various authors have discussed the relative stabilities of the α- and β-polypeptide structures [346, 426]. Schuringa and Algera [460] have commented on the nature of the membranes of the Allwörden sacs. Haselmann and Zahn [398] have discussed the fibrillar polyphase nature of the scale cells. Mahal, Johnston, and Burns [422] have investigated the relation between scale structure and dimensions and fiber thickness for a number of fiber types.

Sobue [467] has described investigations on the fibrillar cortical cells produced by the decomposition of wool with trypsin. A staining procedure for delineating the cuticle, cortex, and medulla has been described by Po-Chedley [451]. Pre-oxidation with peracetic acid has enabled Alexander [345] to separate the wool fiber into three subfractions: a subcutaneous membrane insoluble in dilute ammonia, a soluble portion consisting of α-keratin of molecular weight 70,000, and a soluble portion consisting of α-keratin of molecular weight 4,500. Mercer [425] has discussed the ordered linear arrangement of corpuscles which he found in electron-micrographs of the wool fiber. They are identified with the crystalline fraction of the fiber which gives rise to the fiber x-ray pattern. Some of the reflections are orders of the large spacing, and others arise from small-scale molecular features within the corpuscles.

Work on molecular structure has proceeded at an accelerated pace; disagreements between various groups of authors indicate that this trend will continue. X-ray crystallographic studies on amino acids, peptides, and proteins have been summarized by Corey [381, 382] and have led Pauling, Corey, and coworkers [439, 444, 445, 498] to propose two hydrogen-bonded helical configurations of the polypeptide chain. These structures have stereochemically equivalent residues in which interaction distances and bond angles are similar to those found in amino acids and peptides. The amide system is planar. The structures have 3.7 and 5.1 residues per turn, respectively, and each carbonyl and imino group is hydrogen-bonded to the 3rd or 5th amide group removed from it in the polypeptide chain. They have also proposed a hydrogen-bonded layer configuration of polypeptide chains called the "pleated sheet" configuration. Perutz [447, 448] has observed a reflection corresponding to a 1.50 Å. spacing in the x-ray diffraction data for horsehair and other keratins, which is cited as strong evidence in favor of the Pauling-Corey 3.7 residue helix. There has been some discussion [440] as to whether the absence of this reflection indicates that the Pauling-Corey structure is not present. Considerations of intramolecular rotation about the C–C bond in polypeptide chains, and of the stereochemistry of these chains, have led Shimanouchi and Mizushima [430, 465, 466] to propose new structural models for α- and β-keratin. The mechanical properties of wool have been discussed on the basis of these structures. After critically reviewing several existing theories, Kanda [413] has proposed new structures for various fibrous proteins.

Work on polypeptide structure has naturally covered proteins other than wool, and much of this information will be of interest to the textile scientist. The structures studied include collagen [363, 375, 435, 443, 478, 481], muscle fiber [362, 364, 405, 429], feather keratin [365, 442], and globular proteins [441].

The infrared absorption spectra of several amino acids and proteins have been studied [355, 392, 418, 433, 475]. Ambrose and Elliott [354, 385] have shown that these spectra can be used to differentiate between various polypeptide structures. Dannenberg [384] and Kratky and Schauenstein [417] have re-

viewed work on the ultraviolet absorption. New studies on the ultraviolet absorption spectrum of various proteins and polyamides include the following papers [359, 449, 458]. The structure of *N*-methylacetamide, a structural unit of polypeptide chains, has been investigated by Mizushima and coworkers using spectral techniques [431] and dipole moment studies [432].

(*c*) Chemistry: Considering the number and diversity of reactive sites in the wool fiber, it is not surprising that research on the chemistry of wool has covered a very wide range of subjects. Much of it has been directed toward practical ends such as rendering wool nonfelting or making it less susceptible to chemical degradation. Brown, Hornstein, and Harris [378] and Alexander, Carter, and Johnson [350] have studied the reaction of formaldehyde with wool to reduce its susceptibility to alkali damage. The effect is presumably due to the formation of new cross-links which are labile to acidic or hydrolytic conditions. The reactions of wool and silk fibers with 1,3-difluoro-4,6-dinitrobenzene and 2,4-dinitrobenzene have been described by Zahn [480]. Alexander and coworkers [349] have studied the esterification of carboxyl groups in wool and the effects of esterification on the dyeing and on the mechanical properties of the fibers. Jones and Lundgren [411] have shown that the modification of wool with β-propiolactone probably takes place *in situ* by an "anchored" polymerization on various reactive amino acid side-chain groups. This modification has a profound effect on the rate and degree of felting of fine wool. The polymerization of methacrylamide in wool has been investigated by Boardman and Lipson [372].

Alexander and coworkers have continued their studies on the reactions of oxidizing agents with wool [351]. The kinetics of the reaction of wool with aqueous chlorine solutions indicate that the rate-controlling process is diffusion across a surface barrier [353], which is believed to be the subcuticle rather than the epicuticle. The tyrosine in wool was found to be in two fractions which differed in their reactivities towards oxidizing agents [352]. Organic chloramines can oxidize wool by two different mechanisms, although in neither case does reaction occur via the intermediary of free chlorine in solution [347]. The oxidation of wool with chlorite and chlorine dioxide has been reported by Schirlé and Meybeck [459]. Blackburn and Lowther [370] have studied the action of formic and performic acids on wool.

The amount of reduction of the combined cystine of wool that is caused by reaction with sodium bisulfite under various conditions has been investigated by Schuringa, Schooneveldt, and Konings [461]. The rebuilding of the original cross-links by rinsing in water was also studied. Huggins, Tapley, and Jensen [404] have discussed the effect of urea on the reactions between —SH and S—S groups in proteins. In connection with studies on the depilatory activity of sodium sulfide, Crewther and Gillespie [383, 390] have shown that over the pH range 10 to 13.5 logarithmic relation exists between pH and sulfide concentration in solutions causing a constant amount of wool degradation. Stricks and Kolthoff [473] have measured equilibrium constants for the reactions of sulfite with cystine and with dithiodiglycolic acid.

Gerstner [389] has compared the behavior on wool of the dye acids and the colorless acids. The wool solubilization products, which are produced during dyeing in media of different pH, have been studied [450]. The use of proteinaceous agents to protect wool from deterioration during dyeing was described by van Overbeke, Mazingue, and Laloy [437]. Serra and de Matos [463] have reported that yellow stains often found in wool are due to decomposition of cystine residues by high temperature and alkalinity. Bradley and Easty [376] have shown that wool can selectively absorb one of two optical antipodes. Enzymatic digestion of wool has been studied by Blackburn [368], who used papain, and by Stoves [472], who used trypsin.

Analytical techniques that have been described include a method for the identification of free carboxyl groups in peptides [474] and a method for the separation of amino acids and polypeptides by paper chromatography of their dinitrophenyl derivatives [367]. Marinelli [490] has reported on the chemical composition of wool and silk. The relations between the amino acid compositions of a wide variety of keratins have been discussed [371]. Vallee [476] has studied the scouring of wool. Publications on wool grease have been concerned with its refractive index [457] and with methods of preparing cholesterol [394], lanolin [395], and high molecular weight glycols [403].

(*d*) Physical Properties: A bibliography and review of work on the mechanical properties of fibers and muscles has been published by Pryor [452]. Ripa and Speakman [455, 470] have studied the creep

of wet wool fibers and concluded that the rate of unfolding of molecules in the crystalline phase is related to the sulfur content of the fiber. The recrystallization of animal fibers after mechanical working was studied by Jagger and Speakman [409]. Bogaty, Sookne, and Harris [374] have reported on the mechanical properties of wool in solutions containing salt and acid. The mechanical properties of both muscle and hair in solutions of organic substances were studied by Pasynskiĭ and Blokhina [438].

The influence of wool fat on various properties of the wool fiber has been investigated by Kjellstrand [415], who concluded that wool fat affects the physical properties of the fabric primarily by acting as a lubricant between the fibers. In two papers on methods of measuring wool fineness, Anderson and Palmer [356, 357] have discussed the effect of noncircular cross section when using the profile method, and the effect of the hygroscopicity of the medium used in making up slides for the projection microscope method. Jacobi [408] has studied the wettability of wool and found that pure wool, freed from all soluble matter deposited in and on the fiber, is water-repelling. The measurement of "whiteness" of wool has been discussed by Selling [462], and Hohls [401] has reported on measurements of the specific gravity of Angora wool. Johnston and coworkers [410] have investigated the relationship between staple length in grease wool and in the resultant top. They concluded that measurements of unstretched staples of grease wool more nearly represent the average fiber length of top than do measurements of stretched staples. Several writers [421, 423] have discussed methods for evaluating a given type of wool.

Both physical and chemical methods for measuring modification and damage to wool have been described. Blackburn [369] has reviewed the chemistry of wool and methods for observing changes caused by processing. A technique for measuring damage to wool with lactophenol-cotton blue reagent has been reported [416, 456]. Mersereau and Rainard [428] have discussed color changes in wool during processing. Burte [379] has suggested that a ratio of mechanical properties measured wet to those measured dry can be used to detect chemical modification in animal fibers. Various methods for measuring the effect of alkaline attack have been evaluated by Binder [366], and Sørensen [469] has described the alterations in wool fibers caused by the decatizing of woolen and worsted fabrics. Whewell [477] has briefly reviewed a variety of methods for assessing damage in wool materials.

(*e*) Felting and Shrink-Resistance: Rath and Fröb [453] and Bogaty, Sookne, and Harris [373, 468] have investigated the relationship between feltability and single-fiber properties. The latter authors have shown that feltability in any given medium can be quantitatively related to the resilience and the D.F.E. of the single fibers. Alexander, Carter, and Earland [348] have shown that surface attack on the disulfide bonds is not in itself sufficient to render wool nonfelting. Lindberg and Alexander [420] have discussed previous work of Alexander ([1507] in the 1950 "Review") on the felting of permanganate-treated wool. The hardening process used in felt manufacture has been studied by Frohnsdorff and Whewell [388]. Methods of increasing the abrasion-resistance and decreasing the felting shrinkage by the application of linear synthetic polyamides to wool have been described by Jackson and Lipson [406, 407]. Jones and Lundgren [412] have shown that treatment of wool with β-propiolactone increases the degree and extent of felting. Several reviews on fiber friction and the mechanics of wool felting have been published [358, 396, 434].

2. Silk.—An historical review of developments in the science and technology of silk has been presented by Howitt [486]. The formation of silk fiber by the silkworm has been investigated by Mercer [491]. Electron micrographs of preparations from the fiber indicate that it is made up of fibrils intermediate in size between molecular and microscopic dimensions. The submicroscopic structure of silk fibroin has also been discussed by Hegetschweiler [485]. After critically reviewing several existing theories, Kanda [413] has proposed a new polypeptide structure for silk. Pauling and Corey [498] and Shimura [502] have also discussed the molecular structure of fibroin and have proposed new models. Schauenstein [499, 500] has investigated the absorption spectra. A theoretical density, in good agreement with the apparent density measured when silk is immersed in water, has been calculated by Moncrieff [492]. X-ray investigations of silk which has been chemically treated have been described by Kratky and coworkers [489, 506]. The relation of sericin, cuticulin, and fibroin in the constitution of raw silk has been discussed by Gallese [484]. Signer and Glanzmann [503] have fractionally precipitated fibroin from lithium rhodanide solutions and have shown that it has a broad distribu-

tion of molecular weights. Bamford and coworkers [482] have discussed the mechanism of the solution of silk in concentrated salt solutions.

The chemical composition of silk has been studied by Marinelli [490]. Inoue and Kudô [487, 488] have discussed the determination of carbohydrates in silk and have discovered the presence of a new glycoside. Using paper-partition chromatography, Shaw and Smith [501] have examined the amino acid composition of sericin. Oku and coworkers [493–497] have reported on various methods for the fixation of sericin of raw silk.

Bryant [483] has studied the effect of adding sulfated cetyl alcohol to the raw-silk soaking bath, and Sumiki and coworkers [504, 505] have investigated the strengthening of silk fiber by treatment with drying oils and organic acids.

3. Regenerated and Synthetic Protein Fibers.—The possibilities of producing synthetic or regenerated wool have been discussed by Moncrieff [529, 530] and Barker [512], and some of the problems involved have been outlined. Traill [537] has reviewed work on the production of regenerated protein fibers. Elliot [517] has discussed the preparation of Ardil fiber from peanut protein. The possible methods of producing a regenerated silk fiber have been reviewed [520, 539], and two methods for resolubilizing silk have been described [531]. Mercer and Olofsson [528] have reported sedimentation and diffusion studies on a soluble derivative of wool keratin. A "plastein" produced by enzymatic synthesis from the enzymatic hydrolysates of proteins has been described by Virtanen [538].

There have been many publications on the chemistry of synthesizing polypeptides. Advances in the synthesis of peptides have been reviewed by Nicholls [532] and by Wieland [540]. Koshland [527] has studied the reaction of acetyl phosphate with some amines and amino acids and has discussed the relationship of the observed reaction rates to the mechanism of peptide bond formation in biological systems. Bresler and Selezneva [513] have described the synthesis of polypeptides by the condensation of amides of hydroxy acids. The use of the Lossen rearrangement to form polypeptides has been discussed by Hurd and coworkers [523, 524]. Kenner [526] and Channing, Turner, and Young [514] have studied the carbobenzyloxy method of peptide synthesis. The use of 2,5-oxazolidinediones in polypeptide synthesis has been investigated by Farthing and Coleman [515, 516, 518]. Other peptide syntheses and synthetic polypeptides have been described [507, 509, 521, 522, 536, 541]. Methods for cross-linking proteins have been reported on by Pinner [534] and by Fröhlich [519]. Isemura and coworkers [525] have studied monomolecular surface films of synthetic polypeptides.

The general interest in the structure of proteins is reflected in the work on the molecular structure of the synthetic polypeptides. Pauling and Corey [533] have applied their helical configuration for the polypeptide chain to several of the synthetic materials of Bamford and Hanby, but the latter did not feel that the application was valid [510]. Perutz [448] has presented evidence in favor of the Pauling and Corey structure. Bamford and Hanby [511] and Ambrose and Elliott [508] have studied the x-ray diffraction and polarized infrared spectra of synthetic polypeptides, and have shown that the polypeptide chain can exist in a folded and an extended configuration. Robinson and Bott [535] have discussed the relation between optical rotation and chain folding in synthetic polypeptides and gelatin.

D. Structure and Properties of Synthetic Fibers—Harris M. Burte

1. General Papers.—Loasby [550] has written a very extensive review of the development of the newer synthetic fibers, whose properties have been summarized and compared by Koch [549] and Tsuji [551]. The physical and chemical properties which make synthetic fibers useful in industrial textiles have been discussed by Williams [553].

Goldstein [545] has considered the relationship between the chemical constitution and the physical properties of synthetic fibers, and Happey [546] has discussed the role of crystallinity and orientation in the formation of fibers from polyethylene, polyamides, and polyesters. Kast [547] and Wenderoth [552] have considered orientation in high polymers and the mechanism of cold drawing. George [544] has presented evidence that the mechanical strength of filaments may be correlated with the dimensions of small domains in the structure of the fiber. The effect of side-chains on the orientation and properties of linear polymers, such as polyurethans and polyamides, has been investigated by Brewster [543]. Koch [548] has shown that the angle of torsion at which fibrous materials break is characteristic of the structure of a fiber and is especially sensitive to differences in structure produced by varying the stretch used during

manufacturing. Bozza and Bonauguri [542] have outlined a technique for determining the optical anisotropy of synthetic fibers.

2. Polyamides.—Several papers have discussed the present position of polyamide fiber production in Europe [558, 577, 579], and Matthes [573] has investigated the chemistry of the polymerization of polycaproamide, which has been the main type of polyamide produced abroad. Japanese workers have reported the changes in crystallinity and orientation produced in polycaproamide fibers by temperature changes [563, 565, 572, 578] and by elongation [562, 564, 566]. The crystal structure [576] and thermal expansion [559, 568] of polyamides have also been studied. Hydrogen bonding in nylon and polycaproamide has been considered by Cannon [556] and Champetier and coworkers [555, 557]. Abbott [554] has measured the extension of nylon filaments under constant load both at 65% R.H. and in water; he has also observed the extent of the recovery following load removal. Watanabe [582] has prepared 89 and 88 nylon and measured the mechanical properties of fibers produced from them.

The hydrolysis of nylon [574, 575] and polycaproamide [571] has been investigated, and the molecular weight fractionation of the latter [569] has been used in studying the mechanism of its condensation polymerization [570, 581]. Elöd and Fröhlich [561] have made an investigation of the relationship between the viscometric molecular weight of polyamides and their uptake of dye, acid, and alkali. Potentiometric titration techniques have been used to measure end-groups in polyamides [580] and to determine the composition of hydrolysates of mixed polyamides [560]. Haslam and Clasper [567] have also reported on the titration of polyamide hydrolysates, and Zahn and coworkers [583, 584] have investigated the chromatographic analysis of these materials.

3. Other Fibers.—The characteristics of polyethylene terephthalate (Terylene, Dacron) fibers have been summarized and described in a number of papers [585, 586, 592, 594, 595, 600]. The synthesis of these fibers [604, 605], their x-ray diffraction [597], and their thermal degradation [598] have been studied.

The Japanese fiber Vinylon, which is made of polyvinyl alcohol treated with formaldehyde, has been compared to other fibers [603], and its pilot plant manufacture has been described [601]. Studies have been made of the conditions suitable for the formaldehyde treatment [588, 606, 607] and its effect on the x-ray diffraction pattern of the treated polymer [590]. The effect of ultraviolet light on this fiber has also been investigated [591].

The possibilities for the polyvinyl chloride fibers in the textile field have been set forth in several papers [587, 589, 593, 596, 602]. Ree, Chen, and Eyring [599] have investigated mechanical damping in Saran fibers and presented some theoretical consideration of this phenomenon.

Zahn has studied the x-ray structure of polyurethan fibers [608] and the analysis of their hydrolysates by paper chromatography [583, 584].

E. High-Polymer Studies—Thomas F. Evans

1. Physical Properties.—The mechanical properties of high-polymeric materials have received considerable attention recently, particularly in the fields of stress relaxation and dynamic measurements. Ter Haar, in a series of papers [648, 649], has applied Sips' theory to several simplified models. Experimental data from stress-relaxation experiments have been used to determine relaxation spectra, and dynamic measurements have also been considered. Müller has reviewed the general field of mechanical properties [633]. The Nutting equation, $\epsilon = \psi\sigma^{\beta}t^{n}$ (where ϵ = strain, σ = stress, t = time, and ψ, β, and n are material constants), has been applied to creep and dynamic data for several polymers [611]. Dynamic measurements, accompanied by infrared spectra and swelling measurements, have been reported for a series of styrene-butadiene copolymers [637] over a range of temperatures; the effects of polymer composition and structure were investigated. Dunell and Dillon [615] have measured the dynamic properties of viscose, acetate, nylon, feather keratin, silk, and polyethylene over the frequency range 1–100 c.p.s. Their results have been related to stress relaxation through a distribution of linear elements [650]. Lethersich [629] has measured the creep and dynamic properties of a number of materials and has related the measurements with a hyperbolic distribution of relaxation times. Wolf [654] has shown the similarities between data obtained from torsional vibrations and dielectric data. Ferry and his coworkers have extended their investigations of high-polymer systems with dynamic measurements on solutions of polystyrene and polyisobutylene [618, 644]. For polyisobutylene the results have been combined with stress-relaxation data on the solid

polymer to give a picture of the relaxation spectrum from 10^{-5} to 10^{6} sec. Other papers describing equipment for dynamic measurements or having general interest to workers in this field [317, 621, 622, 628, 634, 636, 639] have also appeared. Ultrasonic velocities in an assortment of polymeric materials have been reported [635].

Sips has integrated his equation for the propagation of a one-dimensional disturbance in an elastic-viscose medium ([528] in the 1950 "Review") for two particular cases: steady periodic motion, and the propagation of an initially localized disturbance in an initially unstressed medium [646]; and he has extended the theory from the one-dimensional case to three dimensions [645]. Some special cases are considered in detail and lead to the prediction that for incompressible high polymers at small deformations, the same creep and relaxation functions should be obtained when the material is subjected to extension, torsion, or bending. Tobolsky and coworkers have investigated the stress-relaxation behavior of polyisobutylenes of different molecular weights over a wide temperature range [609, 610]. They found large differences in the relaxation behavior at different temperatures, leading to the conclusion that a distinctly different mechanism is operative at low temperatures from that present at temperatures between 30° and 100°C. Dyson has studied the dielectric relaxation [616] and the tensile creep [617] of a series of plasticized polyvinyl chloride polymers over a range of temperatures. Kuhn [627] has considered the problem of evaluating the relaxation time spectrum from stress-relaxation data, and has calculated the expected dependence on molecular weight. Experimental results were found to be in approximate agreement with theory. Gross has extended his theory of linear reversible creep to include permanent deformations [620]. Wall and Flory [651] have reviewed the conflicting statistical theories of rubber elasticity in an attempt to clarify the current confusion in the field. A theory of rubber elasticity involving the non-Gaussian character of the network structure has been formulated for two-dimensional stretching [624]. An apparatus for obtaining constant stress-elongation data has been described [613]. Measurements of the stress relaxation and rigidity of gelatin gels indicate a distribution of relaxation times between 10^{3} and 10^{6} sec. at normal temperatures [632]. Changes with temperature and aging time were studied. The effects of swelling agents on mechanical properties have been studied, using vulcanized rubber [614]. The results were discussed in terms of the intermolecular forces.

The general theory of stress-strain relationships has been extended by Green and Shield [619], who have considered the torsional deformation of an isotropic incompressible cylinder, and by Oldroyd [638], who has discussed the thermodynamics of elastic deformations without the assumption of isotropism. Rivlin [642] has applied his theory of large elastic deformations to several specific types of experiments, using thin sheets, strips, and cylinders of rubber as experimental materials. Rivlin has also reviewed briefly the theory of large elastic deformations as applied to rubber [641] and has considered theoretically and experimentally the strains around a hole in a thin sheet [643]. Crawford and Kolsky [612] have measured the birefringence of strained polyethylene at a series of temperatures in an attempt to differentiate between molecular flow and reversible orientation. The results were interpreted on the basis of crystallite orientation. The behavior of flow markings during dead-weight loading has been the subject of an investigation by Kauffman and George [626]. In a study of the effect of strain rate on the stress-strain properties of polystyrene, Hsiao and Sauer [623] have found a small increase in modulus and maximum stress with increase in the rate of straining. Stepanov [647] has considered the development of local fractures as limiting the tensile strength of oriented polymers. Watanabe [652] has investigated the elastic modulus of polyamides containing rings. The adhesion of synthetic rubber to viscose rayon tire cord treated with various reagents has been studied [640]. *Meta*-phenylenediamine was found to be particularly effective.

The physical changes occurring during the transition region of glassy materials have been reviewed by Jenckel [625]. Mandelkern and Flory [630] have studied dilatometrically the melting points and second-order transitions of four cellulose esters. Two second-order transitions were observed with each polymer. Weir [653] has determined the compression of a number of polymers at pressures between 1,000 and 10,000 atmospheres. All the curves were smooth with the exception of that for polytetrafluoroethylene, which showed a transition at 5,500 atmospheres. The temperature at which a high polymer becomes tacky has been described [631] as a characteristic nonequilibrium property of the material.

2. Polymer Structure.—In a recent book by Frith and Tuckett [659], particular attention has been given to the physical properties and structure of high polymers. Tchen [680] has calculated the perturbation on the distribution function for the configurations of a chain molecule resulting from interactions by neighboring chains. The theory of Montroll ([476] in the 1950 "Review"), which treats the volume effect as a problem of Markoff chains, has been questioned by Suzuki [679]. The allowable configurations of a polymer chain have been considered on the basis of a random walk on various lattices, and bounds have been determined for the number of nonoverlapping configurations [658]. Duclaux [657] has indicated the similarities in the constitution of organic and inorganic macromolecules.

Several general and theoretical papers about x-ray diffraction patterns formed by high polymers have appeared in the past year [661, 663, 667, 672, 682]. The scattering due to statistically disordered lattices has been examined by Hosemann [664] in an attempt to explain x-ray scattering in high polymers. Meibohm and Smith [671] have made measurements of small-angle scattering from samples of several polymeric materials which had been subjected to various relaxation conditions. They were led to the conclusion that two- or three-dimensional structures of a size larger than previously supposed may be responsible for the ordering observed. Samples of a nylon varying in molecular weight from 26,000 to 200,000 gave identical small-angle patterns. Krimm and Tobolsky [668] have applied quantitative x-ray techniques to the study of crystallinity and the orientation of crystallites in polyethylene over a range of temperatures. Stretching the fibers to small extensions caused orientation of the crystallites without change in crystal size, while the orientation at high extensions (100% and over) was accompanied by a decrease in crystallite size. These authors have also studied the patterns produced by a variety of polymers and the changes in structure occurring at the second-order transitions of polystyrene and polymethyl methacrylate [669, 670]. Kasotochkin [666] has studied the change in crystallization of rubber with time of vulcanization. The effect of deformation on the crystal structure of asbestos fibers has been investigated [676]. Distler and Pinsker [656] have used electron diffraction and x-rays to study the structure of stretched and unstretched polyvinyl alcohol films.

Infrared spectra provide another means which has been quite widely used recently in studying polymer structure [677, 681]. Spectra of ethylene polymers have been studied to determine the extent of chain branching, unsaturation, and the presence of oxygen-containing groups [655]. Changes in the double-bond frequencies of natural rubber have been studied during chlorination [675]. From the weakening of the band at 11.9 μ and the appearance of a band at about 11.0 μ, it was concluded that a double-bond shift occurs readily under the conditions of the reaction. Sutherland and Jones [678] have applied polarized infrared radiation to rubber and the two forms of gutta-percha. They found that the three materials have very similar spectra in the amorphous state but that there are marked differences among them in the crystalline state. The importance of infrared spectra in studying crystallinity is indicated. Polarized radiation has also been used to study the structure of aligned specimens of polyethylene, nylon, polyvinyl alcohol, polyvinyl chloride, and polyvinylidene chloride in the 0.8–2.5 μ region [660]. An attempt has been made to assign various types of vibrations to observed bands. Janeschitz-Kriegl [665] has considered the problem of determining optical data for crystals of polymeric substances. He has solved the problem of determining the optical anisotropy of dry, highly oriented fibers, but was unable to obtain a solution for the case of swollen fibers when form double refraction interferes. Richards [674] has observed that paraffin wax crystals are oriented when grown on the surface of cold-drawn polyethylene or polyethylene sebacate, but are not oriented when grown on oriented gutta-percha, rubber, polyethylene terephthalate, or nylon. The distribution of the angles was found to be narrower than the angular distribution of crystalline regions determined by x-ray measurements in the polymer as a whole. Hydrogen nuclear moment studies using the magnetic resonance technique have been conducted on several polymers over a range of temperatures [662]; nuclear moment variations with vulcanization, copolymerization, crystallization, swelling, and molecular weight were investigated. Discontinuities in the nuclear moment were observed for several polymers at temperatures near the discontinuities in the linear thermal expansion coefficient and specific heat. Price [673] has calculated the degree of crystallinity from density measurements for polyethylene and polychlorotrifluoroethylene.

3. High-Polymer Solutions.—Isihara [691–694] has calculated the second virial coefficient for osmotic pressure for several special molecules. Nakajima [706] has treated polymer solutions like regular solutions by introducing an effective coordination number for the segments and an effective concentration for the polymer. Measurements of the osmotic pressure of polyvinyl acetate solutions, using five different solvents [703], showed significant departure from the theoretical equations of Flory and of Huggins. The partial molal volumes of several linear polyesters in benzene have been found to be constant up to a concentration of 10 g./l. [683]. Heats of dilution of polyvinyl acetate in several solvents have been compared with the heats of mixing of analogous low molecular weight substances to obtain an estimate of the degree of coiling of the polymer molecules [704]. Calculated molar volumes agreed closely with observed values. The specific volume of polystyrene has been determined in chlorobenzene and bromobenzene at 25°C [690] and the results compared with bulk density measurements.

Several recent papers have dealt with the mathematical or theoretical interpretation of rheological data [686, 701, 713, 715]. Observations have been made on single rigid particles in a velocity gradient [714]. Their motions have been found to agree well with Jeffery's theoretical equations. Solutions of polyelectrolytes have received attention, in particular because of their relationship to such natural products as proteins. Wagner and Long [716] have studied a polymer of vinylpyridine and acrylic acid in aqueous solutions as a function of pH and the concentration of added electrolytes. The viscosities of polyacrylic acid solutions containing added salts have also been investigated [702]. Katchalsky [699] has studied polymers of vinylpyridine and methacrylic acid at various concentrations of polymer and neutral salts and at various pH's. As expected, the viscosity is lowered by the presence of foreign ions, and is a minimum at the isoelectric point. He has also calculated the electrostatic field energy from statistical and electrostatic considerations and obtained agreement with data derived from potentiometric titrations. Linear polyamides have been found to exhibit polyelectrolytic behavior in concentrated formic acid solutions, and to a very much smaller extent in 100% sulfuric acid [711]. The change of dielectric constant of polar molecules under the influence of shear has been investigated [688]. The value usually was found to decrease, although for solutions of ethyl cellulose an increase in dielectric constant was observed. Nonpolar polymers showed no changes. Cellulose nitrate in acetone solutions has been found to exhibit an abnormally narrow region of dispersion [712]. An explanation based on a solvated chain molecule in the form of a loosely held random coil was put forward. Kuhn [700] has studied the relaxation of polymer molecules in solutions after removal of an electric field in which they had been oriented, and observed a spectrum of relaxation times which showed an increase to a limiting value with increase in molecular weight. Debye and Bueche [687] have proposed the use of dipole moments for obtaining information on details of the hindered rotation in polymer chains. They have developed the theory for the effect and have applied it to parachlorostyrene.

Other papers concerning polymer solutions have dealt with light-scattering theory and methods [707] and the theory and application of flow birefringence measurements for determining whether a given polymer acts as an oriented rigid rod when under shear or like an elastic sphere [684]. For polystyrene the latter explanation appeared more reasonable. Viscosity, sedimentation, and diffusion measurements on methylated polyphenylenes have indicated that these polymers also do not react as rigid rods [685]. The spreading of thin films of polymethyl methacrylate and of polystyrene has been investigated [709]. The data are interpreted on the basis of a feltlike structure of entangled coils. The solubility of cellulose acetate propionate in organic solvents and the properties of films formed from various solvent-diluent-plasticizer combinations have been reported [708]. It has been shown that heating to 100°C at atmospheric pressure for several days is insufficient to remove the solvent from benzene solutions of polymethyl methacrylate or polystyrene, whereas polyvinyl acetate can be dried under these conditions due to its low softening point [689].

A concerted study of the depolymerization produced by ultrasonic waves has been made by Jellinek and White. They have developed a theory of the reaction [695] and applied it to experiments on polystyrene. Although a reasonable agreement was found for the distribution of molecular weights after various periods of irradiation, the dependence of the rate on the initial chain length could not be adequately explained on the basis of degradation by friction or

impact [696, 697]. The rate was found to depend on polymer concentration in a rather complex manner with an optimum concentration which was a function of the intensity of irradiation [698]. Melville and Murray [705] have shown that the depolymerization of polystyrene and polymethyl methacrylate is much slower when no cavitation occurs. Degradation appeared to proceed by a molecular rather than a radical mechanism. Ultrasonic radiation was found to induce the polymerization of monomeric styrene. The depolymerization of polyvinyl alcohol has also been investigated [710]; a limiting degree of polymerization was observed below which no degradation occurred (see also [696] and [697]).

F. Fiber-Yarn-Fabric Relationships—Helmut Wakeham

1. Yarns.—Schwarz [728] has considered the general theory of yarn geometry in an effort to predict how the properties of fibers will take effect in determining yarn properties. His considerations have led to studies by Finch [720, 721] of the mechanism of interfiber stress transmission in terms of the area of contact between fibers and the distribution of pressures over these contacting regions. This interesting work brings into focus such interfiber friction measurements as those made by Howell [723] in which the whole problem of friction has been viewed.

In the field of cotton fiber-yarn relationships, further attention has been given to the relative importance of fiber length, strength, and fineness in determining yarn strength. Fiori and Brown [722] have spun into yarns fine cottons which had been cut to have a length distribution equal to that of a coarse short cotton. Having thus eliminated length as a variable, they examined the strength and elongation properties of the yarns to find the effect of fineness. It was found that strengths of yarns from fine fibers were less sensitive to twist than strengths of yarns from coarse fibers below the maximum strength point. Above that point the reverse was true, the effects of overtwisting being more pronounced for the fine-fiber yarns. The highest maximum strength was produced with finer cottons, and this was attained at a lower twist multiplier than that required for the maximum with coarse cottons. In a theoretical consideration, Morton [725] has confirmed the relative importance of fiber fineness in producing strong fine yarns. Several statistical correlations of cotton fiber properties with yarn strengths have also been reported [719, 726, 730].

Changes in rayon yarn properties with changes in twist have been reported by Deschacht [718] and Afontchikov [717]. The relation between staple length and spinning limit for rayon has been investigated by Klompé [724].

Roy has discussed the factors which influence the tensile strength of cordage [727].

Relatively little has appeared on the problem of translating fiber properties for blends of fibers into yarn behavior. Wilhelm [729] has summarized the desirable elongation and breaking-stress characteristics of fibers in a blend to produce yarns of various properties.

2. Irregularity of Slivers, Rovings, and Yarns.—Various modifications of evenness or uniformity testers have been described during the past year. These include the mercury feeler gage [743], the pneumatic evenness gage [739], a photographic recording of an optical yarn projection [736, 737], and a mechanical gage for roving [744]. Germans [740] has described a photoelectric integrator and discussed its application to yarn studies. Truitt [747] has described an attachment to evenness testers, permitting accurate measurement of low-twist filament yarns which do not have a round cross section. Several different types of evenness testers have been compared [733, 734], and the accuracy of capacitance evenness meters has been considered in a theoretical study by Mack [741].

The interpretation of yarn evenness data presents problems more difficult than the measurement. Townsend and Cox, in a series of papers [738, 745, 746], have considered this problem in some detail and have shown that the relation between the mean standardized variance and the length within which the variance is measured leads to indices for characterizing types of yarn irregularity which may be of practical importance.

Arañó [735] and Picard [742] have considered the irregularity of sliver and roving, comparing the random distribution with the practical one. Picard's treatment of the subject is a mathematical one in which he derives formulas for the coefficient of variation of local count for both the random sliver and the actual case; the difference is in terms of a coefficient which can be defined by the fiber weight, count (or fineness), and length irregularity. The general expressions permit derivation of the special cases (1) in which the fibers are of constant cross section or variable length, (2) in which the fibers are variable both in cross section and length, and (3) in which

the lengths are variable and are related to cross section.

Vanden Abeele [731, 732] has considered the distribution of fibers in sliver, roving, or yarn from probability considerations. He suggests that the variance component of the number of fibers in the sliver cross section due to a completely random distribution of the fibers be given the same value as that in an ordinary binomial distribution, with a constant probability equal to the mean number of fibers divided by the maximum number in the cross section. Any variance component in excess of this he regards as being caused by other systematic influences.

3. Fabrics and Other Textile Structures.—Three important papers on the relationship between the structural geometry of a textile fabric and fabric properties have been published by Backer. In the first two of these [748, 1117], the subject of mechanical abrasion is treated. It is shown that because the rate of abrasion on a surface is proportional to the applied force of the abradant, fabric structures in which large flat surface areas of the yarns are exposed withstand abrading action much better than ribbed structures in which the load of the abradant is concentrated on a small area of yarn crowns protruding from the fabric. In the third paper [749], it is shown that air permeability of a fabric is related to minimum areas for the interyarn pores and that these areas can be computed to a first approximation by assuming that the textile yarns act as flexible, inextensible, circular cylinders.

Penner and Robertson [760] have also studied flow through fabrics by preparing models of the four types of woven fabric interstices and observing the flow of oil streams through these models. They have shown that the four pore types do not behave like geometrically similar orifices and that the effective pore area is a function of the Reynolds number. This type of analysis is not applicable to closely woven fabrics made from loosely twisted yarns. In this case the interyarn openings are indistinguishable from the interfiber openings, and the permeability of the fabric becomes a function of the fiber properties as well. Thus, in closely woven cotton fabric the pore space distribution has been shown to be related to the maturity of the cotton going into the material [756].

The more subjective properties of fabrics, such as resilience, hand, drape, smoothness, luster, and compressibility, have been related to the fiber properties by Ray [761] and by Hoffman and Beste [755].

Principles of fabric design to achieve water-resistance [764] and dimensional stability [751] have been investigated. Kober [757] has suggested that, as a first approximation, fabrics of different design could be characterized on the basis of their density.

Crease-resistance treatments have received considerable attention both from the point of view of their evaluation [752, 762] and of their effect on the abrasion-resistance of the fabric [753, 759].

Experimental investigations have been made of the strength of fabrics after abrasion [765], of the compressional and tensional strains on tire cords in tires [758], and of the stresses imposed upon fabrics during suspension in finishing [750].

It has been shown that the mechanical hysteresis associated with energy loss is appreciably greater for cotton and rayon tire cords than for the constituent fibers, which suggests that interfiber friction is a major cause of such energy losses under cyclic loads at low frequencies [763].

A bibliography of the published literature on the translation of inherent fiber properties into textile structures has been prepared [754].

G. Sorption, Swelling, and Diffusion—Howard J. White, Jr.

1. General Papers and Theory.—There has been little work on the classical thermodynamic theory of sorption, although Hill [778] has clarified his work on "adsorption thermodynamics" and "solution thermodynamics" and related his ideas to those of Everett ([676] in the 1950 "Review"). Several papers concerned with multilayer adsorption isotherms have appeared. These were designed to obviate some of the drastic approximations made in the BET theory. Halsey [776] has devised a new multilayer isotherm, taking account of the long-range attractive forces of the adsorbent which are active in the multilayer region and discussing various types of nonuniform surfaces. A difficulty in interpreting the assumptions of Halsey's paper has been pointed out by Hall [775], and the equations have been further discussed and amplified by Halsey [777]. Attractive forces extending beyond the first adsorbed layer were also studied by McMillan and Teller [783, 784], who took into account the surface energy of the adsorbate as well. Barrer and Robins [770] have developed a multilayer isotherm using a modified van der Waals' equation of state for the adsorbate. They have also discussed capillary effects in terms of this model. Theimer [786] has critically compared

several theoretical adsorption isotherms. Hüttig, Schreiner, and Klein [779] have examined various changes in the surface of an adsorbent brought about by the presence of other gases, adsorption and desorption, and aging. Jones [780] has studied the various effects possible using a BET isotherm limited to three layers.

Gul [774] has considered the role of intermolecular forces in the swelling of high polymers and has concluded that simplified treatments based on cohesional energy cannot be satisfactory. Münster [785] has reviewed the recent experimental and theoretical advances in the treatment of swelling in high-polymeric materials, particularly in elastomers.

Utilization of the capacity for very rapid arithmetic operations possessed by large-scale computing machines for the solution of diffusion problems has been outlined by King [782]. The method, known as the Monte-Carlo method, consists of the repeated application of the random-walk process to a large number of test particles to build up the concentration profile resulting from the diffusion process. A number of diffusion processes leading to differential equations which cannot be integrated may be evaluated in this way. Babbitt [766] has developed a generalized approach to diffusion which interprets gaseous, liquid, solid, and surface diffusion in terms of a single dynamical equation. The problem of a substance which diffuses into an absorbent in which it is destroyed by a first-order process has been treated by Danckwerts [773] for a variety of absorbent shapes. Crank [771] has discussed diffusion processes for which the diffusion coefficients vary discontinuously with the concentration. Crank and Park [772] have considered various anomalies known to exist in diffusion processes occurring in high polymers and their possible interpretation mathematically and in terms of molecular structure. A general review of diffusion in elastomers has been given by Barrer [767].

Three interesting papers on flow through porous or particulate beds have appeared by Jones [781] and Barrer and Grove [768, 769]. Various possible vapor phase and surface diffusion processes were enumerated and their experimental differentiation and evaluation discussed.

2. Interactions with Simple Liquids and Vapors.— Preston, Nimkar, and Gundavda [800] have examined the retention of water in capillary spaces between fibers in centrifuged samples. They were able to interpret their data in terms of classical capillary theory and found that, even in the case of viscose rayon, up to 25% of the total water held was present in interfiber capillary spaces. Thus, a severe limitation in the use of centrifugal methods to determine imbibition within fibers is indicated. The same authors [801] have also studied the alterations in the absorptive properties of fibers resulting from thermal pretreatments. The general problem of water absorption and its importance in processing have been reviewed by Muus [799]. McLaren and Rowen [797] have discussed recent experimental and theoretical advances in the treatment of water absorption by polymeric materials with particular emphasis on proteins.

Treloar [805] has studied the effect of tension on the absorption of water by horsehair by a gravimetric method. The observed increase in absorption with increased tension contradicts the decrease presumed by White and Stam ([61] in the 1949 "Review") from swelling measurements on human hair. The absorptive properties of a number of amino acids and di- and tripeptides were determined by Mellon and Hoover [798]. They found that amino acids which crystallized into well-developed lattices did not absorb water below the solution point, but that all varieties of absorption phenomena, including hysteresis, could be found with relatively simple compounds. Katchman and McLaren [795] have measured the sorption isotherms of a number of polymers and proteins to try to determine the relative efficiency of site adsorption by polar groups. Vermaas [806] has discussed swelling, heat changes, mechanical changes, and other phenomena important in the study of absorption by fibers.

Reviews of the absorption and swelling of cellulose fibers have been given by Barkas [787] and Escard [790]. Chêne and Rochet [788] have used a thermobalance to follow the rate of drying of cotton and various wood pulps. Grinberg [793] has studied the effects of hydrolysis and ultrasonic irradiation on the sorption of water by cellulose. In each case a decrease in sorption occurred. Rollins, Fort, and Skau [803] have compiled a selected bibliography on the swelling of cotton and its utilization in water-resistant fabrics.

Forward and Palmer [792] have offered some possible explanations of the data of Abbott ([660] in the 1950 "Review") on the swelling of cellulose acetate. Hoshino and Yumoto [794] have examined the absorptive properties of a variety of baked and drawn nylon and polycaproamide fibers, and determined the

differential heats of absorption. The swelling of polyvinyl alcohol has been studied by Priest [802]. Farrar, Neale, and Williamson [791] have criticized the use of specific volume measurements for the determination of "bound water."

Crank and Robinson [789, 820] have used an interferometer to study the influence of concentration and orientation on the diffusion of several liquids into cellulose acetate. A marked increase in diffusion coefficient occurred at a volume concentration of penetrant of about 60%–70%. Mandelkern and Long [796] have studied the rate of sorption of methylene chloride and acetone by cellulose acetate as a function of vapor pressure, film thickness, and temperature. A summary of the water vapor permeability, diffusion, and sorption of organic film-forming materials has been made by Thomas [804].

3. Interactions with Solutions.—Chouteau and Lenormant [808] have presented infrared spectrographic evidence for the fixation of bivalent ions, such as those of copper, magnesium, and calcium, by the peptide linkage of acetylglycylglycyl-*N*-ethylamine. Klotz and Urquhart [812] have used spectrophotometric methods to study the binding of protons and anions by serum albumin, and Alberty and Marvin [807] have used a moving boundary method to demonstrate the combination of chloride ions with serum albumin. Pasynskiĭ and Chernyak [814] have studied the sorption of urea, guanidine nitrate, urethan, and water on serum albumin, γ-globulin, and wool keratin, and found Langmuir isotherms with a clear zone of saturation. Eckstrom [809] has followed the swelling of single human hair fibers in ammonium thioglycolate and the deswelling by potassium bromate. The results show that the reduction of disulfide bonds follows closely the penetration of the thioglycolate solution.

The absorption of strong and weak acids by casein and zein fibers has been discussed by Elöd and Fröhlich [810]. Hudson and Schmeidler [811] have shown that wool at pH 2 is a low-capacity anion exchange medium. The rate of exchange was found to be governed by diffusion. König [813] has studied changes in swelling and the mechanical properties of viscose rayon after various acid and formaldehyde treatments.

4. Experimental Methods.—The use of dielectric measurements at microwave frequencies to measure water bound by hydrogen bonds to proteins has been discussed by Haggis, Buchanan, and Hasted [817]. Auerbach [815] has found that by placing an electrode within a gel and another in an external solution, a potential analogous to a streaming potential could be measured when swelling occurs. He also found that application of a current in this system altered the swelling. Oswin [819] has devised a method for the rapid comparison of the water-vapor permeability of films. Robinson [789, 820] has developed an interferometric method of studying diffusion and swelling in transparent high polymers by determining the concentration of diffusant from the fringe system developed. Barrett, Joyner, and Halenda [816] have discussed a new method of determining surface area and pore volume from nitrogen desorption isotherms and have compared the method to the mercury porosimeter method [818]. The agreement was close for a variety of inorganic adsorbents.

H. Dyeing—Howard J. White, Jr.

1. Properties of Dyes and Dye Baths.—Seidenfaden [848] has presented a review of the structure and properties of many new dyes, and Kunz [838] has reviewed the development of dyes of the Indanthrene type. Recent trends in the development of azo dyes have been discussed by Adams [821], and the formation and characteristics of Neolan dyes have been reviewed by Widmer [850]. Oda and Urata [845] have considered the synthesis of *m*-aminostyrene and its possible use in making polymerizable or polymeric dyes.

A review of the application of wave-mechanical principles to the light absorption and photochemistry of dyes and other molecules has been given by Bowen [822]. Kuhn [837] has extended his methods of determining the color of dyes from the energy states of electrons in boxes of certain shapes. Dewar [826] has studied the relation between color and constitution of basic dyes by the molecular orbital method.

The influence of structure on the color of indigo and related dyes has been discussed by Knott [834], who has also formulated a general color rule [833]. Knott and Williams [835] have discussed the effects of certain structural changes on the color of cyanine dyes, and Jeffreys and Knott [830] have considered abnormal color changes in *bis*-2-(3:5-diphenylpyrrole) methins. Theilacker and Schmid [849] have prepared several triarylmethane dyes of the biphenyl series and considered their properties from the stand-

point of resonance theory. Lutskiĭ [841] has suggested that the color of several organic compounds may be caused by internal hydrogen bonding. Wyman and Brode have studied the visible and ultraviolet absorption spectrum of a number of purified thioindigo dyes in benzene and chloroform [823, 852] and in sulfuric acid [824]. The dyes were observed to exist as *cis* and *trans* isomers in equilibrium in solution and the isomers were isolated. In sulfuric acid, solvation effects changed the spectra considerably.

Several papers have appeared presenting experimental details on the separation and purification of dyes by chromatography. Wool and cellulose dyes have been considered by Zahn [853], vat dyes by Rao, Shah, and Venkataraman [846], and sulfonated azo dyes by Hanson and Gould [829]. The use of ion-exchange resins for purification of direct dyes for cotton has been discussed by Richardson [847].

Lotichius and Kooyman [839] have developed a rapid colorimetric method for the determination of indigo. Gapchenko [828] has considered the advantages of using vanadium chloride rather than titanium chloride in the reductive titration of azo dyes.

Buzágh and Komáromíné [825] have found that triphenylmethane dyes form surface films in water solution, either spontaneously or on the addition of electrolyte. The foaming ability of dyes and the correlation of this property with surface activity has been examined by Nakagaki [842], who has also considered the effects of electrolytes on foam formation by solutions of Congo red [843] and triphenylmethane dyes [844].

Elöd and Fröhlich [827] have discussed the measurement of the dissociation constants of acid dyes and the relationship between dissociation and water-fastness. Luszczak and Zukriegel [840] have observed a correlation between the ultraviolet absorption spectra of dyes and their lightfastness, and Kozlov and Sidneva [836] have studied the lightfastness of madder lakes of alizarin derivatives.

The complex between *o,o'*-dihydroxyazobenzene and copper (II) has been examined by Jonassen, Cook, and Wilson [831]. Wittenberger [851] has considered the structure and properties of the compounds of dyes with metals, and Justin-Müller [832] has reviewed the chemistry of iron and copper salts and their application to dyeing.

2. Color and Its Measurement.—Discussions of the principles and techniques needed for the characterization of color have been given by Mougeot and Niederhauser [865] and Wright [868–870]. King and Rodbell [863] have developed an experimental subjective color comparator, and Ellis [857] has described a photoelectric instrument.

Lancaster [864] and Selling [866] have considered methods of characterizing color and the relationship of color value to amount of dye as applied to the textile industry. Davidson and Luttringhaus [856] have developed a *Munsell Color Book* for textiles, and Davidson [855] has extended and evaluated methods of predicting the color of dye mixtures on textiles. The relationship between the perceptability of color changes and their acceptability to users [860] and an improved method of measuring color differences [858, 859] have been developed by Godlove. Godlove has also discussed the uniformity of grading of American, British, and German lightfastness standards [861] and the relationship between dye strength and visual stimulus [862]. Von Beckerath [854] has pointed out that dyeings which appear equal under certain conditions of illumination may appear different under other conditions, and Thomas [867] has proposed the use of conditionally equal dyeings of this type for evaluating artificial daylight.

3. Interaction of Dyes with Fibers.—

(*a*) General: The Society of Dyers and Colourists has published the proceedings of a conference on "The Tinctorial Arts To-Day" [906]. Papers on the historical development and present status of a wide variety of dyeing processes are included.

Millson and Turl [899] have developed an instrument for following various dyeing processes microscopically through use of a small cell and a flow system. An automatic photometer for measuring the rate of absorption of dyes from solutions of constant concentration has been described by Chamberlain and Lister [877]. Braüer [876] has examined the effect of sonic and ultrasonic vibrations on dyeing and found that rapid mixing of the dye bath and increased speed of penetration of the fabric are achieved.

(*b*) Cellulosic Fibers: Atkinson and Hoyle [873] have considered the reduction of diazotized amines on cotton. Armfield [872] has examined the reduction of direct dyes in dye baths at the boil and has attributed the reduction to the presence of alkali. The tinctorial properties of a series of azo dyes on cotton have been determined by Křepelka and Rais [892].

Mann and Richardson [894] have considered the influence of various cations on the direct dyeing of

cotton and have found that definite differences in equilibrium absorption occur with different cations. Faure and Coupat [880] have discussed a series of dyes which dye cotton well from acid solution for possible use on cotton-wool blends. The effects of temperature and time on the uniformity of viscose rayon dyeing have been studied by Köster [891]. Gailey [886] has examined the factors in the mercerizing and bleaching processes which may cause unlevel dyeing in cotton.

Fowler, Michie, and Vickerstaff [883] have dyed cotton to equilibrium at 40°C with a variety of vat dyes and determined their affinities. They have also concluded that the leuco form is not appreciably aggregated in solution at 40°C. Haller [889, 890] has also studied the vat dyeing of cotton and viscose and the appearance of dye particles in hollow spaces within the fiber under certain conditions. The use of aftertreating agents to improve the fastness properties of dyes on rayon has been discussed by Paulus-Gyöngyössy [901].

(*c*) Protein Fibers: The acid and substantive dyeing of wool has been reviewed by Fröhlich [885], and acid dyeing of native and artificial protein fibers by Weber [913]. Olofsson [900] has titrated wool with hydrochloric acid and sulfuric acid in the presence of various chlorides and sulfates, and has concluded that the anions were absorbed on specific sites. Shippee and Skinkle [905] have studied the effects of agitation on the acid dyeing of wool. The effect of the structure of anthraquinone dyes on their affinity for wool has been examined by Mathey [895]. Veller [910] has considered the dyeing of wool with indigo carmine in the presence of sulfuric acid using varying acid concentrations, dye concentrations, and ionic strengths. The effect of wetting agents on the exhaustion of dye baths for wool dyeing has been investigated by Bhat, Kothare, and Nadkarny [874], and Flamant [882] has discussed the use of soluble protein material to protect wool from degradation during acid dyeing. Mayston [896] has discussed the use of premetallized wool dyes. A multi-unit laboratory apparatus for the study of wool dyeing has been described by Clapham *et al.* [878].

(*d*) Synthetics and Blends: A survey of research on the dyeing of synthetic fibers has been given by Vickerstaff [911], who has also summarized [912] some of the advantages of synthetic fibers as research tools, such as readily alterable physical structure and denier. Allard [871] has discussed the pigmenting of synthetic fibers before extrusion. The dyeing properties of blends containing regenerated protein fibers have been outlined by Tattersfield [908].

Nylon dyeing has been reviewed by Douglas [879]. McGrew and Sharkey [897] have found that uneven drawing and changes in the number of amine end-groups can cause uneven dyeing of nylon filament yarn, and they report that the unevenness can be minimized by a dilute bath. Fröhlich [884] has noted a sharp increase in amount of acid dye absorbed by polyamides below pH 3. Serchi and Naldini [904] have reported the application of self-coupling reactions of aromatic amines to the dyeing of nylon and wool, and Grundy [888] has discussed the dyeing of various nylon blends.

Feild and Fremon [881] have studied the use of copper ions to improve the dyeing of fibers made from acrylonitrile, and Woodruff [915] has discussed the preliminary work which has been done on the dyeing of Acrilan acrylic fiber. Meunier [898] has described the dyeing properties of Orlon acrylic fiber and Dacron polyester fiber, and Lyle, Iannarone, and Thomas [893] have investigated the high-temperature dyeing of these two fibers.

The relation between the orientation of acetate fibers and the dichroism of adsorbed dyes has been studied by Morey and Martin [323]. Rosset and Paris [903] have related the degree of solvation of partially saponified acetates to their dye uptakes, and Sutton [907] has noted several unusual observations on rates of dyeing of acetate in various dye baths.

(*e*) Printing: A review of research in printing has been given by Turner [909]. Turner and coworkers have continued their investigation of the fundamental processes involved in printing with studies of the effect of thickener composition on dye transfer [902] and of the transfer of Indigosols to cellulose during steaming [875]. Greene, Klein, and Fordemwalt [887] have applied their analytical method for vat print evaluation ([813] in the 1950 "Review") to a variety of printing problems. Woodruff [914] has discussed the effect of emulsion stability on color values obtainable by pigment printing methods.

4. Properties of Dyed Materials.—Standard tests for lightfastness [916] and washfastness [922] have been reported by committees of the Society of Dyers and Colourists, and Desai and Giles [920] have made a comparison of fading rates by the Society's lightfastness standards. A new design for a fading lamp

has been described by Boulton and Guthrie [917]. Van den Heuvel [921] has modified the Fadeometer to provide improved temperature and humidity control. Davies and Marney [919] have reported a comparison of the I.C.I. and Munsell standards for staining assessment in fastness testing. A study of the effects of fabric construction and mercerization on the lightfastness and washfastness of vat dyes has been presented by Stradley *et al.* [925].

Speke [924] has reported on the drying condition which can lead to dye migration on fabrics. Couper [918] has examined in considerable detail the gas and light fading of 1,4-*bis*(methylamino)-anthraquinone on cellulose acetate. Evidence for each of several possible decomposition mechanisms has been found. Schaeffer [923] has stated that thermal effects may be more important than photochemical action when a dyed material is exposed to light under laboratory conditions. Tisdale [926] has discussed the effect of natural dyewoods on the tensile strength of nylon yarn.

I. Viscosity and Related Studies of Molecular Weight—Helmut Wakeham

The molecular weights of fiber substances are important determinants of the chemical and physical behavior of fibers, and changes in molecular weight are indications of changes in properties or degradation. The present section deals with progress in molecular weight determination, and especially with viscometric methods because these are usually of the greatest ease of application.

1. Fractionation.—The most complete description of the molecular weight of a high polymer is obtained by a determination of the distribution of chain lengths. No method known gives the true distribution, but, by separation of the polymer into fractions of narrow molecular weight ranges, an approximation of the distribution can be obtained. Studies have been reported of the fractionation and molecular weight determinations of polyvinyl acetate, alcohol, and chloride films [929], and of cellulose [931, 932, 934, 935]. Heuser and Jørgensen [930] have pointed out that in the case of cellulose substances, the distribution of chain lengths originally present in the plant material is "still a matter of conjecture" because all methods of separation and solution are known to cause degradation of the material. Emery and Cohen [928] have suggested that even cellulose nitrate in acetone solution may undergo degradation.

An important theoretical study of the nucleation of polymer chains during precipitation has been published by Morey [933]. Cleverdon and coworkers [927] have investigated the mathematical analysis of fractionation data and advocate the method of Beall whereby each fraction is represented by negative binomial distribution whose constants are fitted by the method of moments.

2. Viscometric Methods.—Several improved viscometers have been described. One of these is a coaxial-cylinder apparatus of very large diameter [957], while another of this type can be driven either in steady rotation or in harmonic angular oscillations of known amplitude and frequency [969]. Woodward has described a vibrating-plate viscometer [985]. The details of the design of twelve viscometers have been considered by Umstätter [980]. In the capillary viscometer kinetic energy effects, end-effects, drainage errors, and pseudoplastic effects of high-polymer molecules have been shown by Hall and Fuoss [952] to be linear in driving pressure; this observation suggests an empirical analysis of viscosity data to eliminate all of these difficulties.

Considerable attention has been devoted to the problem of obtaining reliable viscosity data on solutions of cellulose and cellulose derivatives [961, 966, 986]. The use of wetting agents has been found to increase the rapidity with which the cellulose can be put into solution [959, 978]. Wilson [983] and Conrad and coworkers [944] have studied the effect of rate of shear on the viscosity values obtained with cuprammonium and cupriethylenediamine solutions of different cellulose concentrations. Calvert and Clibbens [941] have examined a number of equations used in calculating the intrinsic viscosity of cellulose in cuprammonium solution and have concluded that the Martin modification of the equation by de Jong, Kruyt, and Lens fits the experimental data well over the whole range of relative viscosity up to 100. A discussion of the interpretation of viscometric data for cellulose in cuprammonium solutions has also been given by several Russian workers [954]. Almin [936] has suggested that more accurate intrinsic viscosity values can be obtained by preparing the cupriethylenediamine solvent from stock solutions immediately before use. Other sources of error in the viscometric method have been discussed by Parisot and Cyrot [971].

Problems inherent in determining the intrinsic viscosity of nitrocellulose have been discussed by Lindsley [958] and by Moore [963]; other workers have been concerned with the Staudinger constant for this material [953, 965].

Of interest in this connection are the more important works on the theoretical aspects of high-polymer solution viscosities. Several authors have approached this problem by considering spheres suspended in liquids [946, 974, 981]. Peterlin [972] has developed a statistical model of short-chain polymers in which he has calculated the intrinsic viscosity of a solution of flexible molecules, including terms for the hydrodynamic interaction between the chains. Kirkwood and Auer [956] have found that three-fourths of the stationary intrinsic viscosity of rodlike macromolecules can be ascribed to their rotatory diffusional torques. Flory and Fox [947–949] have estimated the root-mean square distance separating the ends of polystyrene and polyisobutylene molecules from intrinsic viscosity considerations. These authors have also proposed an empirical method for estimating the intrinsic viscosity for a polymer at zero rate of shear [950]. The concentration dependence of viscosity in dilute solutions of macromolecules has been considered by Bawn [937] and Riseman and Ullman [973]. De Wind and Hermans [984] have developed a method for the study of the non-Newtonian behavior of dilute polymer solutions; Scheele and Timm [976] have found a relation between the temperature dependence of the non-Newtonian flow of long-chain polymers and their freezing temperature.

Cutler and Kimball [945] have reported on the effect of adsorption on measurements of viscosities of very dilute polymer solutions. Mandelkern and Flory [960] have derived an equation for the dependence of the diffusion coefficient on the concentration in dilute polymer solutions; on the basis of this relationship, the authors show that it is wrong to assume that the diffusion coefficient varies linearly with concentration. Bondi [940] has considered the relation between the thermal conductivity of liquids and polymers and the pressure coefficient of viscosity. Contrary to the assumptions of Flory and Fox, the presence of a low polymer in the solution has been shown to have a distinct effect on the measured viscosity molecular weight of a high polymer [942]. Various theories of the flow behavior of high polymers have likewise been tested by studying the intrinsic viscosities of solutions of polystyrenes of known molecular weights in various solvents [938, 939, 982]. A number of general papers in the field of rheology are of interest in the determination of the molecular weight of high polymers [951, 955, 962, 964, 967, 968, 970, 975]. Studies of flow birefringence of high-polymer solutions have been reported by Conner and Donnelly [943] and by Scheraga, Edsall, and Gadd [977]. The interdependence of apparatus and solution parameters which are important in measuring structural viscosity has been demonstrated by Steinmann and Tromm [979].

3. Other Methods.—Several improved methods of osmometry have been described in the recent literature [987, 988, 990, 993, 994, 996, 999]. One of the most interesting is a rapid dynamic method described by Philipp [1003]. This method has been employed by him to study the characteristics of various membranes in measurements on solutions of cellulose acetate in acetone [1004]. Lang [998] has made a comparison of two formulas for evaluating osmotic pressure measurements and has found that for nitrocelluloses of one million molecular weight the variation between the two may be as great as 55%.

A study of temperature effects and the nature of the solvents on the osmotic pressure of cellulose nitrate solutions has been reported by Meerson and Lipatov [1000]. In a theoretical study of osmometry Staverman [1007] has shown that measurement of osmotic pressures with membranes of different porosity permits determination of the entire molecular weight distribution of the solute.

One important reason for making osmometric measurements is to obtain molecular weight values which may be compared with those obtained by the more rapid viscometric method and to permit evaluation of the Staudinger constant. Such comparisons have been reported for nitrocelluloses [1001], cellulose acetate [1005], polystyrene [988], and polyacrylic acids [989]. An osmometric technique has been described by Immergut and Mark [996] for lower molecular weight polymers and for higher temperature measurements.

Molecular weights from sedimentation equilibria have also been compared with the results of intrinsic viscosity determinations for cuprammonium rayons [997] and cellulose acetate fractions [1010]. The nonideality factor from ultracentrifuge measurements has been compared with that obtained from osmometry for polystyrene fractions by Wales [1008] and by Wales, Adler, and Van Holde [1009].

Light-scattering methods for the measurement of molecular weight of high polymers in solution have received wide attention in the literature [991, 992, 995, 1002, 1006, 1011].

J. Deterioration of Materials—Richard Steele

1. Microbiological Deterioration.—A general review of recent research on microbiological damage to manufactured materials, including textiles, has been made by Greathouse, Wessel, and Shirk [1018]. The attack on cellulose by microorganisms has been the subject of an exhaustive monograph by Siu [1031] and of briefer reviews by Moncrieff [1026] and Chesters [1014]. Pigman [1029] has presented a survey of the cellulases and related enzymes, and Husemann, Loës, and Lötterle [1021] have described a technique for measuring the activity of such enzymes. Whitaker [1033] has purified a specimen of a mold cellulase. Wegener and Questel [1032] and Ames [1013] have investigated fungi which can damage textiles, and several groups of workers [1019, 1027, 1028, 1030] have studied soil bacteria which attack cellulose. Dickerman and Starr [1015] have described a suitable medium for isolating cultures of cellulolytic bacteria. Hall and Elting [1020] have found that an increasing amount of cotton bought in the open market appears to show damage from microorganisms. This damage has been ascribed by Kerr [1022] to wet weather, a factor which has also been studied by Marsh, Guthrie, and Butler [1025]. Abrams [1012] has found that the mildew-resistance of cotton duck apparently increases after weathering, and Fynn and coworkers [1016] have attempted to correlate natural and accelerated weathering tests on this fabric. Goldthwait, Buras, and Cooper [1017] have investigated the effect of partial acetylation or methylenation on the resistance of cotton to microorganisms. In a study of the enzymatic hydrolysis of cellulose, Levinson, Mandels, and Reese [1023] have found that cellobiose is one of the principal products. Macmillan and Das [1024] have described a method for determining copper in proofed jute.

2. Mothproofing and Miscellaneous.—Several reviews of mothproofing have appeared [1035, 1039–1041, 1046, 1047]. Lotmar [1043] has investigated the effect of Mitin on moth larvae, and Borghetty, Pardey, and Sherburne [1037] have studied mothproofing agent-detergent combinations. Lamb [1042] has discussed a new procedure that can be used with tests of mothproofing efficiency and in which either the loss in fabric weight or the weight of larva excrement is measured.

The problem of damage to cellulose during bleaching has been discussed by Zwicky [1048] and Caille and Cuvelier [1038]. Schönberger [1044] has described the development of agents which protect cellulose, particularly rayon, against oxidative degeneration during vat dyeing. The deterioration of organic polymers and synthetic fibers by light [1045], aging [1036], heat, and weathering [1034] has also been reported.

K. Detergency and Surface Activity—Richard Steele

1. Detergency.—Swanston and Palmer [1068] have reviewed the historical development of the theory of washing action, and the present economic status of soap and synthetic detergents has been discussed by Snell and Kimball [1065]. The uses of nonionic surface-active compounds in the textile industry [1062, 1063, 1072] have been outlined. Smit [1064] has discussed the washing of linen textiles, while McKee and Roseberry [1057] have studied soil removal from nylon. Stüpel and von Segesser [1067] have discussed the use of secondary alkyl sulfates as bases for heavy-duty detergents. The action of builders in detergent compositions has been considered in several papers [1055, 1058, 1061, 1069, 1071].

The problem of soil-fiber interaction on cotton has been examined by Compton and Hart [1050] and by Utermohlen, Ryan, and Young [1070]. The ways in which substances used in the finishing of fabrics can affect their susceptibility to soiling has been discussed by Hall [1051]. The distribution of detergent molecules on the outer surface of fibers has been considered by Stüpel [1066]. Weatherburn and coworkers [1060] have measured the sorption of various types of synthetic detergents on carbon black.

The current laboratory techniques for evaluating detergents have been reviewed [1049, 1052, 1056], and new instruments for use in such evaluations have been proposed [1054, 1074]. The use of artificially soiled fabrics in detergency testing has been studied by Reutenauer and Dupin [1059] and Harris and Brown [1053]. The transmittance of laundered soiled cloth has been correlated with its reflectance by Walter [1073].

2. Wetting.—Gruntfest [1077] has suggested a resolution of the wetting process into the mechanically hindered escape of occluded gas and the advance of

liquid into the material being wet, the latter being a physicochemical process. The nature of the surface being wetted and its role in determining wettability has been emphasized by Dervichian and Lachampt [1076] and by the work of Schultze [1081]. The effect of temperature on the activity of wetting agents has been viewed by Lucas and Brown [1079], and Lange [1078] has investigated the relationship between rate of wetting and the age of the wetting solution. The effect of pH on the rate of surface tension lowering has been determined by Burcik and Vaughn [1075]. Shapiro [1082] has reviewed recent progress in testing wetting agents; Stüpel and von Segesser [1083] have discussed the alkylsulfosuccinates; and Schäfer [1080] has suggested an equation of state for surface films of wetting agents.

3. Analysis of Surface-Active Agents.—Numerous schemes for analyzing surface-active materials have appeared [1084, 1085, 1088, 1093, 1094, 1097, 1098, 1102]. Caswell [1087] has reported on the determination of quaternary ammonium compounds, and Weatherburn [1100] has described a modified method for determining alkyl sulfates. The use of the salicylaldehyde test for surface-active agents has been studied by Weber [1101], particularly for its application to detergent mixtures containing polysaccharides. Studies on the quantitative determination of surface-active agents by dye titration have been reported by Klevens [1095]. Tests for cationic soaps [1091], polyglycolethers [1090], and inorganic phosphate builders [1092, 1096] have been described. The determination of carboxymethylcellulose by the anthrone method has been proposed by Black [1086], and Walther [1099] has suggested a simple method for measuring the oxygen in laundry and bleaching baths. An automatic apparatus for measuring the frothing or foaming of surface-active agents has been devised by Götte [1089].

4. Miscellaneous.—The formation of micelles in solutions of surface-active agents has been considered in several papers [1103, 1104, 1107, 1109]. Harkins, Krizek, and Corrin [1105] have studied the effect of micelle formation on the absorption spectra of some pyridinium salts. Raison [1108] has found that foam on sodium oleate solutions contains an adsorbed layer of acid soaps, the composition of which depends on the concentration of the soap solution. Vapor pressure lowerings for a series of detergents have been determined by Huff, McBain, and Brady [1106] using a thermistor method.

L. Test Methods and Apparatus—D. J. Montgomery

1. Geometrical and Mechanical Properties.—

(*a*) Single Fibers: Interlaboratory comparisons of measurements of fiber dimensions have been presented by Palmer [1166–1168] and others [1113]. Monfort and Rey [1164] have discussed comparison between length measurements made with the Schlumberger apparatus and those made visually by buyers. Giovanelli [1130] has given a new method for the measurement of the mean diameter of fibers in a bundle, and Fyfe [1127] has described an optical projection method for measurement of fiber length. Honegger [1142] and Karsch [1145] have discussed determination of staple diagrams for fibers. Köb and Stiepel [1149] have considered fineness measurements on fibers by means of air permeability. Scott, Barrett, and Rollins [292] have investigated a test for measuring various cottons in fibrous form for their suitability in making swelling-type, water-resistant fabrics. Larose [1153] has brought forth a method of electrostatically orienting fibers when their diameter is to be determined microscopically. Monfort and Neirynck [1163] have listed methods of counting the fibers in yarn cross sections.

The effect of gage length on single-fiber mechanical measurements has been reviewed by Phillips [1169] and by Fritzsche [1126]. The tensile recovery behavior of textile fibers has been treated by Susich and Backer [1175]. An improvement in technique in the Pressley fiber-strength test has been reported by Hessler and Power [1138].

(*b*) Fiber Assemblies: Irregularities in the dimensions of fiber assemblies have been considered by Foster [1123] (cotton yarn irregularity and high drafting); Gregory [1132] (short-wave variations in cotton rovings); von Grossmann, Masing, and Schubert [1133] (continuous uniformity measurement of picker lap); Lipowsky [1156] (count dispersion tests in cotton and rayon staple yarns); and Townsend and Palmer [1178] (variation of woolen yarn number). Monfort [1162] and Rusca [1171] have discussed the interpretation of evenness measurements made with the Uster Tester. The W.I.R.A. [1115] has devised a roving levelness tester. Van Nes [1165] has described a synchronized stroboscope for observing details of operation of ring twisting machines. Monfort [1161] has proposed a method for determining nep count in top, and Röder [1170] has con-

sidered measurement of the properties of fibers which govern spinning.

The mechanical properties of yarns have been examined by Matthes [1158] (method for evaluating yarns); by Alexander and Munden [1112] (testing yarn against specification); by Klompé [1147] (strength of spun rayon yarn); and by Schumacher [1173] (measure of processing quality by means of force-extension data). Work absorbed in stretching or breaking yarns has been measured by Lang [1152] with a ballistic pendulum, and by Haner [1135] with an electronic integrator. Apparatus for obtaining force-elongation curves has been described by Wegener [1180, 1181], Frank [1124], Bobeth [1118], and others [1114]. Kramer [1151] has measured crease properties of rayon threads. Devices for measuring tension during processing have been presented by Mintrop [1160], Wolters [1184], and Kolesnikov [1150]. Rusca and Kyame [1172] have described an experimental warp slasher. Lewis [1155] has studied preconditioning of cotton yarn before tensile tests, and Kaswell [1146] has called attention to the need for testing at high humidity. Tachikawa [1176] has described a flex life test for rayon at different loads. Tire cord fatigue has been investigated by Wilson [1183], Budd [1119], Lyons [1157], and Grant, Couturier, and Rhodes [1131].

The testing of upholstery fabrics has been treated by Gebhardt [1128]. A tentative specification for determining shrinkage in knit fabrics containing wool has been prepared [1116], and several machines useful in measuring shrinkage have been described [1122, 1144, 1179]. A theoretical basis for testing the immobility of yarns in woven fabrics has been postulated by Holderer [1141]. The progress of abrasion measurement has been reviewed by Köb [1148] and Buist [1120], and studies on the abrasion test as a criterion of wear-resistance have been reported by Germans [1129], Zart [1185], Jacobsen [1143], and Stoll [1174]. Abrasion testing machines have been described by Himmelfarb [1139, 1140], Mintrop [1159], Hauser [1136], and Frank [1125]. Backer and Tanenhaus [1117] have examined the relation of structural geometry to the abrasion-resistance of textile fabrics.

Abbott [1110, 1111] has made a study of the measurement of stiffness in textile fabrics. Hebeler, Kolb, Stillman, and Baldt [1137] have developed an electronic flexometer for measuring bending properties of fabrics. Gunther *et al.* [1134] have presented a device to give some indication of the hand of a material. Williams [1182] has attempted to reduce the qualitative descriptions of drape to measurable terms. Lepine [1154] has described an apparatus for determining the permeability of fabric to water, and Bundesmann [1121] has devised improvements on his spray tester for determining water-repellency of fabrics. Tallant and Worner [1177] have assembled an apparatus for measuring thermal transmission of fabrics.

2. Chemical Tests.—

(*a*) Review: the A.A.T.C.C. [1186] has published a manual on analytical methods for a textile laboratory.

(*b*) Identification: Hall and Jones [1195] have prepared a third edition of The Textile Institute's procedure for the identification of textile materials. Giles and Waters [1194] have described a scheme for qualitative identification of finishing treatments on cellulosic fibers. Wolf [1215] has discussed quantitative determination of synthetics in wool blends, and Stock and Scofield [1211] have applied the density gradient column to the quantitative determination of additives to a base material (*e.g.,* melamine resin to wool). Heim [1196] has given more details of his method of analytical separation of cotton from viscose or acetate rayon ([1187] in the 1950 "Review").

Various chemical tests have been described by Edelstein [1191] (barium number); Pennock and Skinkle [1205] (oil content of textiles); Pinte and Pierret [1206] (residual sulfur in viscose rayons); Weiss, Hoffmann, and Lee [1213] (copper in textiles to be rubberized); Ringeissen [1208] (pH of oleic acid emulsions); Hückel [1198] (evaluation of rabbit hair mordants); Matlin [1200] (spot test analysis of cellulosic ash); and Wylezich [1216] (identification of damage).

(*c*) Moisture: General discussions of methods for the determination of moisture in organic compounds, and particularly in textiles, have been given by Willits [1214], Garin [1193], and Muus [1204]. Specific techniques for the textile industry have been proposed by Popp [1207] and by Muus [1203]. Methods of more general applicability have been suggested by Johansson [1199], Mitchell [1202], Milligan *et al.* [1201], and Fetzer [1192]. Shaw [1209] has discussed the use of conditioning ovens for moisture tests, and Henderson and Hunt [1197] have devised a simple humidifying system for a high-

humidity room. Weaver [1212] has made improvements in the electrical measurement of humidity with hygroscopic films.

(*d*) Extraction: Carter [1189] has described an interlaboratory experiment on ether-alcohol extraction of greasy card sliver. Specific techniques related to extraction have been listed by Dickinson and Palmer [1190], Buras [1188], Brauckmeyer [1187], and Stevenson [1210].

3. Studies with Radiation.—

(*a*) Microscopy: Houghton [1226] has dealt with the simple microscopy of the major synthetic fibers, and Stevenson [1233] with that of oiled fibers immersed in aqueous media. Herzog [1225] has explained a staining technique to identify damage in rayon fibers, and Kornreich [1227] has devised new microscopic tests to identify damage in wool and silk. Replica methods for studying the surface of fibers have been revealed by Signer, Pfister, and Studer [1231] for the electron microscope, and by Trillat and Besse [1234] for the ordinary and phase-contrast microscope. New fiber-staining techniques to determine fiber structure are listed by Hall [1222]. A modification of the McMahon microscopic wool medullameter has been made by Belin and Goldstone [1217]. Clark [1219] has contributed a note on weight factors for microscopic determination of the percentage of fiber types.

(*b*) Spectrophotometry and Colors: Stearns [1232] has surveyed the progress of spectrophotometry in the textile industry to 1951. Nickerson [1228] has described an automatic cotton colorimeter, and Fourt and Sookne [1221] have discussed the measurement of reflectance characteristics related to the luster of cotton yarns. Henderson [1224] has reviewed developments in fluorescent lamps, with reference to color problems.

(*c*) Nuclear Radiations: Trotman [1235] and Crompton [1220] have outlined some applications of radioisotopes in textile technology. A related application to fiber tagging in paper pulp has been made by Sankey *et al.* [1229]. A general discussion of the industrial problems in nuclear technology is given by Shamos and Roth [1230]. Thickness gaging with β-rays has been described by Clapp and Bernstein [1218] and by Heller, Sturcken, and Weber [1223].

4. Miscellaneous.—

(*a*) General Articles: Pollitt [1260] has discussed the uses and limitations of textile testing, and Wesson [1264] has prepared a manual of physical testing. Barella [1237, 1238] has described apparatus for textile analysis and control as employed in Spain.

(*b*) Electrical Measurements: Hayek and Chromey have measured the electrical resistance of textile materials [1253], and static electricity on fabrics [1254].

(*c*) Statistical Topics: A general treatment of quality control of materials has been provided in the new *ASTM Manual* [1236], covering presentation of data, limits of confidence, and the control chart method of analysis. Seder [1261] has discussed statistical techniques in industry; their particular applicability to the textile industry has been studied by Wiggers [1265], Enrick [1243, 1244], Hamby [1251, 1252], Noechel [1258], Thomason [1263], Le Duc [1256], Chandler and Lomax [1242], and Graf and Henning [1248, 1249]. Specific techniques in the statistical field have been set forth by Brearley and Cox [1240] (experiment design); Worthington [1266] (method for computing standard deviation); Brownlee [1241] (correlation methods applied to production process data); Goossens [1247] (precision estimation); Graf and Henning [1250] (calculation method for time study); Bennett [1239] (randomness tests); Youden [1267] (locating sources of variability); Goossens [1246] (comparison of combing machines); Olsen [1259] (picker lap tests); Gaus and coworkers [1245, 1262] (mechanical sampling of cotton bales); LeCompte, Keller, and Davis [1255] (experiments with wool sampling devices); and Lund and Alcroft [1257] (sample blending).

IV. Development

The papers in this section are concerned with developments in the fields of mechanical processing and wet processing. In the first division, in which mechanical processing is discussed, papers are reviewed which pertain to opening and blending operations, scouring, carding, drafting, spinning, and weaving. The wet-processing operations, discussed in the second division, include sizing and desizing, bleaching and stripping, dyeing, printing, finishing, and drying.

A. Mechanical Processing—J. H. Wakelin

1. General.—Hentschel [1272] has reported on 15 years of international standardization in the textile industry and in textile machinery construction.

Problems encountered in the mechanization of the silk industry, dealing particularly with the intricate machinery developed to simulate manual operations, have been reviewed by Gallese [1270]. Carter [1268] has reported on the scientific progress in the wool industry, discussing such subjects as steely wool, the Textralizing process, the theory of the mechanism of the felting process, and shrink-resistant treatments for decreasing feltability. Rich and Chase [1273] have emphasized the advantages to be gained by the use of controlled humidification in plant operations, particularly in the processing of wool. The production of static electricity during the processing of wool has also been discussed by Runton [1274], who has indicated that this phenomenon alone is the cause of much bad work and waste. Chandler [1269] and Graham [1271] have investigated various antistatic agents for nylon.

2. Opening and Blending.—The Southern Regional Research Laboratory of the United States Department of Agriculture has developed a cotton opener to make possible better cleaning by equipment already installed in textile mills. Results of tests with this new opener on a pilot plant scale [1278] indicate that the opener does not affect the staple length or cause fiber damage in the cotton. Senior [1279] has described a new type of picking machine developed by Proctor and Schwartz for opening rags and waste. In determining the effect of opening and picking on the staple length of cotton, Oleman [1277] has found that the Fibrograph provides a quick and easy determination of staple lengths of cotton samples in various processes of cotton manufacture. The system used by Shelby Cotton Mills for blending raw cotton stock has been described [1275]. The savings made possible by the use of automatic blending lines have been pointed out by Leineweber [1276] in a discussion of fiber blending studies.

3. Scouring and Fiber Lubrication.—Most of the papers in this section concern the cleaning of wool. Vallee [1309] has discussed the washing of wool as a physicochemical phenomenon. Various methods for scouring raw wool have recently been reviewed [1280], including both the emulsion and solvent methods of scouring. Schofield [1306], in discussing 25 years of scouring and milling, has considered standard woolen and worsted type scourers, the mechanical factors in scouring, and the use of auxiliary products in scouring, together with the problems of milling and the function of soap in this process. The evolution and present status of the wool scouring industry in New Zealand has been described by Smith [1308]. Elliott [1288] has made an analytical survey of the problems of scouring, particularly noting the constitution of vegetable oils and the classifications of anionic and nonionic synthetic detergents. Goodings [1293] has reported on the behavior of mineral oil on wool in relation to wool scouring. Certain aspects of the emulsion scouring of wool have been treated [1284, 1304, 1305, 1307, 1313, 1314]. A practical approach to wool scouring has been described by Birnbaum [1285] in an outline of scouring procedures as part of a review of the types of impurities, equipment, and scouring agents used. The fact that wool shrinkage may vary widely for the same wool has been brought out in scouring tests of 120 lots of wool scoured for the Livestock Branch, Production and Marketing Administration of the U. S. Department of Agriculture, during 1946, 1947, and 1948 [1282].

Mansfield [1300] has developed a method for the low-temperature scouring of greasy wool. Fong, Yeiser, and Lundgren [1289] have described a new method for raw-wool scouring and for grease recovery based on the use of aliphatic alcohols in combination with the natural suint salts removed in aqueous solution during the scouring procedure. Webber [1312] has developed a laboratory model of a four-bowl scouring machine for studying wool scouring. Dickinson and Palmer [1286] have recently described an apparatus for studying mechanical action in the washing of wool.

Methods for general scouring and for tar removal by solvents have been described by Dumont [1287] and Reumuth [1303]. Dangers inherent in the use of degreasing agents of the solvent type have been emphasized by Batta and Scheepers [1283]. Vidal [1311] has described a method for separating vegetable matter from animal fibers which employs a high-frequency magnetic field.

Norris [1302] has reviewed recent developments in the technique of wool scouring and oiling. It has been pointed out that wool oil, used to aid in the processing of wool, may deteriorate leather belts or aprons with which it comes in contact [1299]. A laboratory machine has been developed for studying the accelerated deterioration of leather by various wool oils; the results with this laboratory equipment closely parallel those experienced in mill practice. A review of the recovery, refining, and applications of

lanolin has been made by Gernert [1291, 1292]. Vallee [1310] has considered the role of fat constituents of lubricants for textile fibers. The lubrication of cotton and other textiles has been reviewed by Moss [1301], who has presented data to illustrate the reduction in friction resulting from the addition of lubricants, including paraffin wax, tallow, mineral oil, octadecyl alcohol, fatty acids, and their esters and soaps. Hitchenor [1295] has considered generally the application of oils as lubricants to textile materials. François and Juillard [1290] have reported on the evaluation of red oils employed for the oiling of wool, particularly on their aging characteristics. The development of new water-soluble synthetic textile lubricants in the United States has been discussed recently [1281], and Horne has pointed out that the Germans put great effort into the use of synthetic lubricating oils during World War II [1296]. Götze [1294] has indicated that it is advisable in the shortened spinning process for viscose rayon to follow up the chemical aftertreatment of both knitting rayon and weaving rayon by a preparation with emulsions of oils; emulsions of mineral oils have been found to be suitable both for the knitting and weaving rayon applications. The requirements for spinning oils and lubricants have been discussed by Kadmer [1297], who has given consideration to the characteristics of vegetable and mineral oils, emulsifiers, and stabilizers. Kingman and Coleman [1298] have atempted to assess the relative fire hazards of various types of oil used in the woolen industry and to develop a simple laboratory test for measuring these hazards. They point out, however, that no simple laboratory test can completely determine the actual fire hazard of a given oil under all conditions.

4. Carding.—The development of a new type of short-carding engine for the woolen system has been announced by Carding Specialists Company, Ltd. [1315]. In the field of worsted carding, a review article [1318] has pointed out the arrangement and variation of the standard Bradford card, the Continental card, the French card, the crossbred card, and the twin burring card. Diagrams indicating settings, speeds, and counts and crowns of wire in the clothing for these various types of cards have also been published [1317]. The development of the forepart or the opening arrangements of carding equipment has been reviewed [1319]. Kaupa [1326] has considered the problem of the grinding of card clothing, and the function of the doffer in carding has been discussed by de Swaan [1333]. Kittel has described the machine parts of a card and has discussed the functions that each plays in producing a card web and sliver [1328]; he has also dealt at some length with suitable adjustments of the various machine parts. Crofts [1321] has pointed out that although stripping is necessary at regular intervals to maintain quality in woolen carding, it is advisable to do as little stripping as possible and still maintain efficient carding operations. Crofts [1322] has also considered methods for controlling evenness in wool carding. John [1325] has described a practical gage for measuring cylinder settings in cards. The special care in the carding and combing of short wool fibers has been considered by Saxl [1332] and by Talkenburg [1334].

In the field of cotton carding, Kieke and Hessler [1327] have determined the optimum doffer speed for carding production cotton for coarse goods, and have determined the effect of varying doffer speed on the carded web, yarn, and fabric. Hunlick [1324] has discussed the handling of short bast fibers in cotton and rayon mills, and has pointed out that mixtures of bast fibers with cotton and rayon are possible. Lindsley [1329] has described a method for estimating the extent of fiber orientation in lap and sliver, making it possible to obtain a quantitative evaluation of the effectiveness of carding and drawing operations in aligning fibers. The index developed for this purpose has served to arrange samples taken throughout processing in the following expected order of increasing orientation: card sliver, drawing sliver, finisher drawing sliver, and roving. Combed roving shows almost complete parallelism. In order to obtain laps of identical lengths, the Southern Regional Research Laboratory has developed a knock-off method which can be applied to existing pickers without difficulty [1331]. A pneumatic rack control for pickers has been designed to maintain uniform lap tension [1316].

Cheng and Morton [1320] have described certain of their experiments aimed at determining what happens at or immediately above the front plate, or stripping plate, of the card. They have drawn attention to this part of the carding operation because they believe that the degree of waste removed as flat strips is largely determined at this point. Oleman [1330] has reported a reduction of flat strip wastes by changing the setting of the stripping plate on a card from a clearance of 0.034 in. to 0.024 in. Tests on

yarn show that the change in stripping-plate setting has no appreciable effect on the breaking strength or size of the yarn.

Discussions of nep control have received some attention in the recent literature. Webb and Richardson [1335] have reported on the influence of the nep factor of the card web on yarn appearance; this study included 828 lots of American upland cotton and 2,484 lots of yarn from the test series for selected cotton improvement groups for the crop years 1945–47. Grover [1323] has also reported on the problem of determining the causes of neps in the processing of cotton. He has indicated that the greatest emphasis has been placed on conditions of operation and setting of the cotton card as a source of nep production.

5. Drafting and Spinning.—A review of the published literature on drafting and spinning reveals that no outstanding developments in manufacturing techniques or in the design of equipment have been described during 1951. Most of the papers on drafting deal with the problem of fiber control or with the problem of uniformity of finished product after drawing. An extensive investigation carried out on silk has been described by Wegener [1383] on the influence of the needling of a flat combing machine on the top and noils of long fibers. Pharr [1366] has indicated that proper tension on fly frames decreases roving variations. Ebert [1347] has given a brief description of the construction and operation of Rieter's double drawing frame. Boylston [1343] has indicated how to select drawing frame rolls. Quaas [1368] has discussed new free rollers for the drawing of cotton and rayon, and Reinfeld [1369] has reported on a basis of pendulum loading of pressure rolls for drawing frames.

A brief review of the factors causing irregularities during drafting has been made by Zotikov [1387], and their incidence has been discussed in the light of the probability theory. Defective drafting arising from imperfections in front rollers both in mule and ring spinning frames has been discussed by Gregory and Tyson [1354]. Uniformity in both drafting and doubling has also been discussed by Wegener and Friebel [1384]. Rimette [1370] has discussed the distribution of fibers in a sliver during drawing. Foster [1350] has given a detailed treatment of the motion of fibers in roller drafting. He has pointed out that when the motion of fibers is unstable, the drafting proceeds by successive "breaks" in the fiber so that the fibers leave the front rollers in groups or clots. This succession of breaks constitutes the drafting wave. Foster has considered the theory of the formation of the drafting wave and has extended the theory to calculate wave lengths and amplitudes of drafting waves. He has shown that results based on his theory agree reasonably well with wave length and amplitude results observed in cotton. Irregularities in sliver, roving, and yarn made on the worsted system have been examined by Townend [1375]. He and Chow [1376] have reported an investigation to determine the effect of such factors as the number of operations, doublings, and drafts on the perfection of mixing wool fibers using the Continental system of drawing and spinning. Factors in quality modification during drafting in the zone of limited draft have also been discussed [1353]. Wooding [1386] has discussed fiber control at draft rollers.

The Ambler Super-draft system is now available in the United States through the McGlynn Hays Company [1336], and the new developments in this system have been summarized recently by Hannah [1356]. A description of the Bird Universal Drafting system, capable of producing yarns of all types from fibers varying from 1 to 10 in. in length, has appeared in the literature [1342]. Srivastava [1372] has described a number of different types of drafting systems in spinning frames, and has suggested that the Casablancas double-apron system appears to deal more satisfactorily with a greater variation of fiber length. He has also included in his paper information on recommended drafts for different types of cotton processed on the four-roller system, the single-apron system, and the double-apron system. Mody [1365] has reported on the practical utilization of high-drafting systems, and Ebert [1346] has described three constructions of high-draft flyer frames, giving details of their constructional characteristics.

A survey of the modern trends in cotton spinning techniques and ring frame designs describes various types of high-drafting systems, such as the single-apron and four-line roller systems of Platt Brothers and Company, Ltd., the Casablancas double-apron system, the Saco-Lowell single-apron system, the Dodd-Whitin two-zone system, the Ambler Super-draft system, and the Balmes high-drafting system. In this review [1337] attention is given to the qualitative description of long-range and short-range irregularities and to the drafting wave, including its frequency and amplitude characteristics. Hadwich

[1355] has discussed modern roving ring spinning frames, and Lemon [1361] has reviewed the development of spinning methods from the earliest times to the introduction of automatic machinery.

Farnsworth [1349] has described the P. S. C. system of spinning and twisting, giving information about the containers and tapes, the drafting arrangement, the problem of end breakage, and the doffing and twisting operations. Townend and Whewell [1378] and Frotscher [1351] have compared ring and mule spinning of woolen yarns, and have studied the draft and twist distribution in woolen ring spinning [1352, 1377]. The advantages of using colloidal silica in woolen spinning have been discussed by Teisseire [1373]. McCann [1362] has described pot spinning and its advantages, particularly for the production of worsted yarns. The problem of maintaining quality with the required increase in rate of production in worsted spinning has been considered at some length by Kershaw [1357].

In the field of cotton spinning, Dakin [1345] has reviewed the developments in machinery, while Walz [1382] and Pomfret [1367] have discussed efficiency and productivity. Computations of spinning efficiency have been published by Vora and Shah [1381]. Fahrbach [1348] has reported on single-process cotton spinning, and methods for spinning slub yarns have recently been described [1339, 1380].

In a discussion of the spinning of paper yarns, Thieme [1374] has reported on the production from raw material to the finished yarn, particularly the twisting of the paper bands into ply yarns. A study of a one-step conversion of continuous-filament rayon to spun yarn has been made [1344], and the character and sources of denier nonuniformities were found to be of two distinct types: long-length variations (10–100 ft. long) that arise from nonrandom breaking of the continuous filaments, and short-length variations (1–3 ft. long) that arise primarily from discontinuous drafting of the broken filaments. From the standpoint of appearance, the long-range variations are the more important of the two. Mixing experiments described by Klompé [1358] with rayon-staple fiber on cotton spinning machines have provided information about methods of blending fibers. The homogeneity of a mixed yarn, the mixing of fibers for blends, the advantage of mixing rayon-staple fibers with various fiber deniers, the mixing of bright and dull rayon-staple fiber, and the mixing of rayon-staple fiber with fibers of quite different properties have been considered. Millard [1363, 1364] has described experimental work on the processing of nylon staple on cotton spinning equipment.

Baltz [1341] has investigated the sources of end breakage in spinning, and Schneider [1371] has discussed the influence of the number of fibers in the cross section of a yarn on its irregularity and on the spinning limit obtained in worsted spinning. An easy way to check spinning ends down is described by Leach [1360]. Vincent and Brown [1379] have discussed measurement of end breakage rate, and have shown that a large number of breakage tests must be made to determine the true breakage rate. The advantages of variable-speed spinning, such as provided for by the Brown-Boveri system of spinning control, have been described by Wildhaber [1385]. A new tensiometer for measuring yarn tension during spinning has been developed by the General Electric Company [1184]. The development of endless extensible mule spindle bands free from knots or irregularities has been described as an aid to an efficient drive mechanism and power economy [1338]. The possibility of completely uniform spun goods has been investigated by Köb [1359]. A description of the Scaife lifter motion which can be applied to cap, ring, or flyer frames to produce the type of package required has been made by Audley [1340].

6. Winding and Twisting.—A technological description of the process of doubling and twisting as well as the construction and operation of ring twisting machines has been prepared by Schneider [1396]. Kaufmann [1392] has made a systematic review of weft winding machines in general, in which German, Swiss, and Czech machine designs have been described. The Universal Twister has been described by Audley [1388]. This equipment is in general use for yarns of 3 to 8 ply, and is applicable to a wide range of materials and counts, such as jute, cotton, flax, rayon, woolen, and worsted yarns. A survey of developments in the winding process and in machinery design and types of package has been made by Marsden [1394]. Muschamp [1395] has discussed cone winding for the hosiery industry. Chaya [1390] has reported that it is feasible for cotton-system mills to consider making section beams from rayon cakes. Bodansky [1389] has discussed the maintenance and operation of cotton-system warping equipment as used with magazine-type cone creels. Howell [1391] has emphasized the difficulty of removing defects which have been spun into yarn, and

has advised that it seems desirable to prevent the occurrence of at least a portion of the defects at their source before they are carried into the spinning operation. A simplified method of making twist calculations has been suggested by Kunz [1393].

7. Weaving and Knitting.—An introduction to weaving and related processes has been treated extensively by Robinson [1421]. The report on cotton weaving by the British Cotton Weaving Productivity Team has been published by the Anglo-American Council on Productivity [1407]. The automatic reaching-in machine originally developed for wool by the Wool Industries Research Association has been applied to cotton warp drawing [1398]. Barker [1399], in an article on yarn preparation and weaving, has discussed the processes of winding, warping, sizing, drawing-in, and twisting and weaving. Problems relating to the tension of moving yarn systems [1422], filling defects [1411, 1425], and filling weights [1426] have been described.

In discussing the modern trends in weaving equipment, Cotterill [1404–1406] has described the advantages and disadvantages of two unorthodox loom developments—the shuttleless loom and the circular loom. A report has been made on the performance of a Warner and Swasey Sulzer-type loom installed in an American worsted mill [1417]. The Benninger nonstop shuttle changing loom [1418] and the Fayolle-Ancet circular loom [1397] are new production equipments which have recently been described in the literature. Middlebrook has discussed the primary aspects of the power loom in a review of the principles of weaving [1416]. The development of jacquard equipment has been described by Dracup [1409], and Barrett [1400] has suggested a practical method for "cast-out" jacquard harnesses to adapt looms quickly for production of particular designs.

A number of papers have been concerned with the method of operation of certain loom components and with improvements in the operation of weaving by means of new loom attachments. Halamicek [1412] has made an analysis of the timing and speeds of the shuttle motion on a loom. He has illustrated correct and incorrect acceleration and retardation methods for the shuttle. Lichtenheldt [1414] has given an exhaustive account of the design of loom-sley drive mechanisms, and has discussed in great detail the dynamic and kinematic aspects of sley mechanisms. The theory of possible forms of shuttle movement has also been investigated as a contribution to the rational design of cam-operated picking mechanisms. The mathematical conditions allowing the shuttle to have constant actual acceleration over all or part of its stroke have been given, and details of several compound movements of the latter type have been evaluated [1402]. Thomas [1424] has described the effect on the size of the shed opening of varying the movement of the dwell given to the heald staves and the sweep and eccentricity of the sley. Middlebrook [1415] has discussed negative dobby shedding motions; Zellnik [1428] has shown that use of the electromagnetic dobby can speed sample design variations. The principles for the installation of dobbies to obtain the best quality goods and highest performance from the looms have been outlined by Riesnert and Geuting [1420]. Modifications to the ordinary uncut moquette loom to achieve the production of fabrics having two different pile heights have been described by Cowburn [1408]. Cornely [1403] has described a detailed investigation into factors involved in the operation of several looms by one person. Data relating to personnel and to loom efficiencies have been given, together with formulas for calculating various efficiency relationships.

With reference to knitting, Dutton [1410] has reviewed the contributions which have been made to the design of present knitting machines, and has pointed out that research now being conducted on knitting motions, mechanisms, and optimum structures for hosiery yarns will probably play a very important part in the design of future knitting equipment. An approach to tricot fabric engineering, initiated at the American Viscose Corporation as a long-term research project, has resulted in some new postulates on how varying the runner lengths and ratios affects grey-fabric strength, yield, and courses per inch off the machine [1423]. Weiner [1427] has pointed out that changes in yarn counts, courses per inch, and calendering methods may be made to reduce underwear shrinkage; the major portion of potential shrinkage is introduced during the knitting operation. Certain refinements in technique for achieving quality control for warp knitting have been discussed by Pembroke [1419]. Busch [1401] has described the knitting of imitation fur fabrics on flat jacquard frames, and has discussed in detail the operation of raising. The production of nylon hose from 15-den. monofil yarns has been treated by Hünlich [1413].

8. Yarn and Fabric Properties.—In previous sections of this division on mechanical processing the papers have been concerned with methods of produc-

tion and their effects on the state of aggregation of the material. It is appropriate at this point to discuss those papers which deal particularly with the properties of completed structures, such as yarns and fabrics.

Schwarz [1464] has pointed out that with a well planned and executed group of experiments, the textile technologist can predict the performance of the textile materials from the behavior of the individual fibers from which these structures have been made. As an aid in translating fiber configurations into yarns and fabrics, the use of soluble fibers, such as the alginate rayons, has been discussed by Johnson [1449] and Levesque [1452]. The development, physical properties, and testing of rope have been treated at some length by Kenyon [1451], who has discussed in particular the use of nylon, Terylene polyester fiber, and Orlon acrylic fiber, and the advantages which each offers as rope material. Difficulties in the establishment of a uniform system for the designation of yarn structure, particularly when plied and cabled yarns come under consideration, have been considered by Morton [1458]. The component parts of yarn properties which affect its quality have been reviewed by Goshawk [1444]. Meijberg [1455] has considered quality in terms of rayon yarn; spinning yarns from blends of rayon staple and cotton have been considered by Buisman [1438]. The possibilities of using dope-dyed viscose have been reviewed by Howden [1448], who has pointed out that some rayon and wool blend problems have been eliminated and several new effects have been achieved with this material. Physical data on nylon staple yarns spun on the cotton system from 3-den., 1½-in., semidull nylon staple has been published by Millard [1457]. The advantages of using nylon staple with wool both in woolens and worsteds have been discussed by Garner [1442, 1443]. The use of a blend of spun rayon and Perlon for men's clothing has been reported by Driesch [1439]. The increasing use which is now being made of synthetic fibers blended with natural fibers or used alone has brought forward new problems related to sewing [1465].

In the field of yarn calculations, Blackshaw [1432] has developed formulas which permit calculation of the number of fibers in the cross section of cotton yarns. The influence on yarn characteristics of the law of critical yarn diameter and twist has been discussed briefly by Hermanne [1447]. Diagrams to report yarn utility based on the physical properties of the yarns have been developed by Matthes [1158]. New general formulas have been derived by Porsche [1461] to determine the amount of twist to be imparted in a roving or in a yarn. Pickles [1460] has reported on wool and yarn calculations relating to greasy and scoured wool costs, production of top, drafts and doublings, and yarn counts.

The requirements for new fabrics for the Armed Forces [1429] have been reviewed by Armstrong [1431], Stoll [1469, 1470], and Weiner [764]. Press [1462] has reported on some effects of blend composition, weave variation, and fabric weight on comfort and appearance characteristics of melton. Franck [1441] has discussed textile materials produced by mixing wool with certain artificial fibers, particularly viscose rayon, nylon, and Ardil, on the woolen system. Hardacre [1445] has described some fibers which may be blended with wool, including Fibro, Fibroceta, Fibrolane, nylon, vinyon, and alginate rayon. The properties of materials made from different blends have been compared with all-wool fabrics. Data on the properties of yarns and fabrics made of blends of viscose with wool or cotton have been reviewed by Linder [1453]. Methods of bonding fibers and producing bonded fabrics have been reviewed by Elliott [1440]. A new type of nonwoven fabric containing no bonding agent or no interfiber fusion has been reported by Ryan [1463]. This fabric has a relatively high degree of extensibility and conformability, combined with high porosity and low density; these properties make such a product suitable as a base for coating, saturating, or impregnating.

An apparatus for the measurement of air flow through woven fabrics for permeability determinations has been described by Williams [1471]. A survey has been prepared by de Jong [1450] on the circumstances under which shiners may occur in fabrics manufactured from rayon yarn. He has also described a method of using a shrinkage diagram to find whether a rayon yarn will given rise to the occurrence of shining threads. An extensive study has been made on the effect of construction on the laundering shrinkage of knitted woolens [1433]. Various causes of barre marks in worsted fabrics with some suggestions for eliminating some of the processing troubles have been reviewed by Woolstan [1472]. The preliminary processing of glass yarns and the weaving of glass fabrics have been described by Steiner [1468] and Mahler [1454]. The properties and processing of rayon fabrics have been discussed by Bouvet [1436], Heimeran [1446], and

Nobis [1459]. Smirnov [1466] has discussed the theory and methods of calculating the density of cloth.

Appleyard [1430] has described textile developments in the rubber industry. A number of papers have dealt with the adhesion of rubber and textile materials. Borroff and coworkers have continued their investigation of adhesion ([1519–1521] in the 1950 "Review") and reported further data [1434] on the effect of using yarns made from spun staple fiber. Milde [1456] has reviewed the steps necessary to prepare cord fabrics for the tire industry. Problems in the physical behavior of rubber-textile combinations, particularly in automobile tires, emphasizing deformation, heat balance, carcass strength, and rubber-textile adhesion, have been discussed by Springer [1467]. Boström [1435] has reported on some chemical and physical properties of different types of textile fibers and some of the mechanical properties of cord fabrics made from them. A review of the recent periodical and patent literature on textile-rubber composites, solvents, and cements has been made by Bowden [1437].

B. Wet Processing—K. Lanse Turner

1. General.—Marsh [1488] has written a book designed to fill the need created by the many recent developments in the chemical aspects of finishing. The entire field of fiber finishing has been covered. Turner [1498] has comprehensively reviewed developments during 1948 and 1949 in the wet processing of natural and regenerated cellulose fibers. Bizioli [1478] has discussed the relationship of chemistry to the textile industry. Hartsuch [1482, 1483] has prepared an introductory textbook on textile chemistry and an accompanying laboratory manual. A general correlation of chemical and mechanical factors in textile processes has been presented by Gensel [1481], while a more detailed analysis of the relationships between fabric construction and finishing has been reported by Best-Gordon [1477]. A list of new dyes, textile chemicals, and wet-processing laboratory equipment developed during 1951 has been prepared [1475].

(*a*) Water and Waste Disposal: An adequate supply of good water will always be essential to the wet-finishing industry. Roshard [1495] has described equipment and procedures for softening water for boilers and for washing, bleaching, and dyeing processes. Modern water-conditioning methods and equipment have also been discussed by Buckley [1479], who has emphasized the need of better planning for re-use of water. Alleviation of stream pollution has received scant attention in the literature considering the seriousness of the problem. Murdock [1490] has presented a layout for waste treatment developed for a Southern textile mill whose chief problem was the disposal of small amounts of sulfur dye waste. Recovery of the chemical constituents of kier liquors and dye wastes has been studied by Sabnis [1496], who concluded that it is cheaper to dispose of such materials than to reclaim them. Helmers and Sawyer [1485] have studied the problem of kier waste disposal from the standpoint of nutritional requirements for aerobic biological stabilization. The study has revealed that cotton kiering waste can be treated successfully in mixtures containing as little as 5% sanitary sewage. Recovery of wool grease from scouring liquors, cleaning of scouring liquors for re-use, and patents for the refining and use of wool grease have been described by Gernert [1291].

(*b*) Instrumentation and Control: The wet-processing portion of the textile industry lends itself more readily to instrumentation and automatic control than do other portions of the industry. The relationship of instrumentation to modernization has been discussed by Miedendorp [1489], while Daubert [1480] has illustrated a complete system for controlling all factors in dyeing, including temperature, timing, and pH. Walter [1499] has dealt with automatic process control, covering such processes as wool scouring, sizing, drying, mercerizing, and miscellaneous processes. The influence of automatic control instruments on quality and speed in textile processing has also been covered [1476, 1491]. Special attention has been given to spectrophotometric control of dyeing [1484, 1497]. Patrick [1492] has emphasized the importance of strict control in vat-color aging. The A.A.T.C.C. has prepared a catalog of test equipment and materials [1473].

(*c*) Kiering and Mercerizing: The effects of chemical pretreatment of cotton, concentration of alkali, time of steaming, and the presence of auxiliary substances on the proportion of organic material removed from cotton during an alkali pad-steaming sequence have been presented by Hvattum and Turner [1487]. These authors have also traced the development of modern methods in kiering from some of the earlier discoveries in this field [1486]. Ridley [1494] has discussed the use of a low-range differential pressure

recorder in the automatic control of caustic in the mercerizing range. Methods of achieving greater alkali penetration in mercerization of cotton piece goods have also been presented [1474]. In spite of its higher cost, caustic potash has been found useful for mercerizing blended cotton-rayon fabrics since it does not harden or adversely affect such fabrics [1493].

2. Sizing and Desizing.—Shinn, Sink, and Parker [1518–1520] have prepared an extensive review of the literature on cotton yarn sizing, sizing materials preparation, and practices. Hartgrove [1509] has discussed methods of controlling the amount of size pickup on cotton yarns. As in the past, most of the published work on sizing has been concerned with the problems arising in the manufacture of synthetic yarn. Cook [1506] has explained that size must give certain properties to synthetic yarns in order to be effective. Among these properties are lubricity, abrasion-resistance, strength, stiffness with flexibility, and freedom from static. Materials required to attain these properties in a size for various yarns and end-uses have been developed. MacGregor [1514] has described the various sizes which have been used on continuous filament and spun rayon warps, and has discussed sizing materials and methods. Trends in the sizing and desizing of synthetics have been covered by Bishop [1504]. Cake sizing of viscose and acetate rayon with linseed oil has been analyzed [1515]. The problems arising from this process have been studied, and remedies suggested for the probable causes of these problems. General discussions of acetate and viscose rayon sizing have also been presented [1502, 1503].

The most satisfactory sizing products which have been developed for nylon are based on polyvinyl alcohol or polymethacrylic acid. Problems arising from the use of these materials have been discussed [1505]. A report has been made on a product of the copolymerization of vinyl acetate and allylidene diacetate which on alcoholysis yields a water-soluble material which is useful as permanent size [1511].

The importance of size viscosity and the effect of homogenization have received considerable attention [1500, 1508, 1523]. Kennedy [1512] has compared the effects of boiled and homogenized sizes on coarse, medium, and fine yarns. He has reported that homogenized size will improve fiber lay, give less rigid fiber bonding, retain more yarn elongation, and slightly improve single-end strength. The structure and properties of starch and some of its derivatives have been discussed by Zonnenberg [1524], while Rybakova [1516] has experimented with the breakdown of starch by chloramine-T. Improvements in beam uniformity have been brought about through the use of a new slasher drive [1510].

The variables which influence the activity of enzymes are many. Some of these variables have been outlined [1513], and discussions have been given of various methods used for the desizing of textiles by means of amylolytic and proteolytic enzymes. On the basis of model experiments, it has been shown that with all starch-decomposing enzymes, the rate of decomposition rapidly decreases with sinking temperature. The temperature between 40°C and 50°C is shown to be especially satisfactory for desizing [1521]. Voss [1522] has discussed the use of the amylases in textile manufacturing. Schubert [1517] has taken exception to the view held by Voss on the mechanism of the alphadiastatic hydrolysis of starch. A simplified popular description of the action of enzymes in the desizing of textiles has been presented [1501]. Downey [1507] has contributed a paper which deals with enzymes in textile processing, particularly enzymatic action other than desizing.

3. Bleaching and Stripping.—Optical bleaching agents may be classified as derivatives of coumarin, stilbene, or imidazole according to Sørensen [1546], who has also reviewed the physical and chemical properties of such agents. The results of investigations into the development, application, usefulness, and evaluation of optical brightening agents and fluorescent bluing materials have been discussed in a number of papers [1527, 1540, 1543, 1545, 1547–1549].

The range of bleaching agents has been increased by the use of sodium chlorite [1535]. This bleach, which does not damage cellulose, enables the finisher to bleach delicate cellulosic materials rapidly. Some work has indicated that bleaching with chlorite-hypochlorite mixtures does not offer any advantages as compared with the hypochlorite processing [1538]. However, Baier [1525] has reported that acid is superior to hypochlorite for activating chlorite for bleaching purposes. Other workers have also dealt with sodium chlorite [1533, 1534, 1536]. Meybeck and Ivanow [1539] have studied the resistance to chlorite of metals currently used in fabricating textile equipment.

Bell [1528] has outlined many changes and improvements which have been made in the Du Pont continuous peroxide bleaching system. Other work-

ers have also discussed critical points in the operation of continuous peroxide bleaching ranges, including the caustic-silicate ratio in the peroxide saturating liquor [1526] and the control and instrumentation best suited for various components [1529]. Damon [1530–1532] has contributed a series of articles on the preparation and bleaching of cotton piece goods with particular attention to continuous peroxide bleaching.

The high cost of raw wool has done much to encourage the development of better methods for reclaiming used wool. Wool stripping without the usual chemical degradation has been described by Leonard and Beck [1537], who presented data on fiber strength, alkali solubility, and abrasion-resistance to demonstrate the effectiveness of the method. A continuous method of stripping color from wool carpet-yarn waste on a plant scale in a wool-scouring machine has been reported [1550]. Schandler [1541, 1542] has discussed stripping with reducing agents derived from hydrosulfite. Practical methods of bleaching wool with the hydrogen peroxide dry-in process have been described by Shanley [1544].

4. Dyeing.—

(*a*) Dyes and Their Applications: Smethurst and Carr [1636] have presented a review covering present-day trends in the use of pigment dyes. Newsome [1622–1625] has contributed a rather complete account of logwood and its application. He has discussed particularly the dyeing of blacks on loose wool, and the dyeing of natural silk, nylon, acetate rayon, and wool-Ardil blends. Zuber and Jomain [1654] have described a new method of application for oxidation blacks. Bradley [1567] has discussed the application properties of Coprantine dyes. Recent advances in the application of fast direct dyes on cotton have been made [1643], although vat colors continue in popular use both for cotton and for wool [1615]. A special range of acid dyes has been developed for Perlon and wool-Perlon mixtures [1634]. Many miscellaneous dyeing problems have been studied and reported in the literature. Bittorf [1562] has studied the dyeing of cellulose flock with sulfur dyes, and a new method of forming thioindigo on a fiber has been developed [1632]. Rendell [1627] has determined that the use of oxalic acid as a dyeing assistant contributes to the decrease of the lightfastness of level dyeing acid colors. Young [1652] has given an account of investigations carried out to determine whether diazotized direct dyes developed with Naphthol AS yield dyeings of better fastness to light than when developed with an ordinary developer. The results show that wherever there is an improvement in lightfastness, the increase seems to occur only in heavy shades. Carpenter [1576] has discussed problems in the application of a Sulphon Cyanine R for obtaining a navy blue.

(*b*) Auxiliaries and Assistants: The chemistry of textile assistants and the function of dyeing assistants have been reviewed by Rordorf [1633], Smith [1637], and Lindenmaier [1613]. Theories have been proposed for the retarding effects of polyethylene oxide derivatives on vat dyeing [1604]. The use of sequestering agents in wool dyeing prevents or reduces the formation of trace-metal-dye complexes which are likely to cause dulling or change of shade [1619]. Polyvinyl pyrrolidone may find special use in stripping and in printing with vat dyes, Napthol AS dyes and sulfur dyes, although it has been found to be useless as a swelling agent [1568]. Armstrong [1557] has discussed improvements in fatty acid intermediates available for auxiliaries and finishing agents. Trevor [1641], Singer and Bersworth [1635], and Lesser [1612] have reviewed developments in other finishing and complexing agents.

(*c*) Dyeing Processes: Methods for continuous dyeing of textiles have continued to occupy the minds of workers in this field. Although not a development of the year 1951, the Standfast or molten-metal process of dyeing has been the subject of several papers [1593, 1629, 1645, 1646]. Similarly, the hot-oil dyeing process has received its share of attention [1570, 1647]. Rhodes [1628] has discussed in some detail the necessary characteristics of the oil used in hot-oil dyeing, and has found that white mineral oil is best suited for the purpose. Clark [1581] has reviewed the field of vat dyeing from a practical point of view, and has supplied typical examples and recipes for the application of vat dyes by the Dan River, Williams, pad-steam, and other methods. Filament rayon can now be dyed successfully in package form [1639]. Bonnar [1564] has described a new method for controlled vat dyeing known as the Marhen process, which provides electronic control of the reduction potential which governs dyeing efficiency in the vat dye bath. Gamble [1595] has reviewed briefly various methods of applying vat dyes to fabrics, supplying detailed recipes for preparation of dispersed vat acid (acid-leuco) suspensions which give superior results and quality of dyeing, although they are not

suitable for the production of heavy shades. Lawrence *et al.* [1611] have reported that preliminary tests indicate that it is possible to dye nylon fabrics continuously with acid colors in conventional vat dyeing equipment.

Mechanical features of modern package dyeing machines [1582], advantages and limitations of package dyeing methods [1626], and the principles of package dyeing, preparation of packages, and liquor flow conditions [1578, 1586] have been treated in some detail. Bakker and Borggreve [1558] have discussed the pressure dyeing of spun rayon on conical cross-wound packages. Rinneberg [1630, 1631] has described the mechanical apparatus and typical formulas for loose stock and package dyeing of cellulosic fibers. Hartung [1597] has reviewed the field of high-temperature dyeing. Barth [1559] has discussed the development of modern steaming equipment.

(*d*) Wool, Wool Blends, and Silk: Carter [1577] has tested various dyeing machines under production conditions and brought out a number of interesting points concerning the heating of dye liquors. More general reviews of progress in the field of dyeing woolen piece goods have been presented [1591, 1649]. Weber [1644] has found that if certain critical features are carefully observed, practically all anthraquinone vat colors can be dyed on wool in light, medium, and dark shades (including black) without undue adverse effects on mechanical properties of the fabric.

The problems associated with dyeing wool in blends with man-made and synthetic fibers have received considerable attention during the past year. Advances have been made in formulations for wool-Vicara blends, and the possibility of dyeing mixtures of wool and Dacron has been indicated [1616]. Dyes and methods of dyeing have also been considered in connection with the dyeing of wool-polyamide fiber mixtures [1555, 1584, 1592, 1598, 1599]. Durand and Huguenin A.-G. [1552] has described a new procedure whereby both wool and rayon can be dyed to the same shade with Indigosol colors with improved fastness. Tattersfield [1638] has contributed a two-part article on the dyeing of viscose and wool mixtures. The effect of nonshrink treatments on dye leveling has been studied [1609].

Many wool dyes cannot be used with Ardil because they are sensitive to formaldehyde remaining in the Ardil fiber from the protein-hardening step during manufacturing. However, many level-dyeing acid dyes, acid milling dyes, and pre- and after-metallized dyes are satisfactory for Ardil and Ardil-wool unions. These and other aspects of the dyeing of Ardil have been discussed by Henderson [1601] and Brear [1571].

The scarcity of recent literature concerning silk dyeing is indicative of the extent to which this fiber has been replaced in world trade. However, papers by Thomson [1640] and Tyler [1642] on the dyeing and processing of silk cover the several types of silk dyeing including basic, acid, diazotized, direct, metallized acid, mordant, azoic, sulfur, vat, and other dyes.

(*e*) Synthetic and Regenerated Fibers: the growing influence of technical problems associated with synthetic-fiber processing on research and development is clearly shown by the number of publications appearing in this field. Many reviews of the literature in the field of wet-finishing synthetic yarns and fabrics have appeared [1566, 1579, 1583, 1587, 1589, 1618].

Investigations have been carried out with the object of developing continuous dyeing methods for fabrics composed of the new synthetic fibers—Dacron, Orlon, Acrilan, dynel [1594]. Although the dyeing problems associated with nylon and other polyamide fibers are no longer as acute as they once were, this subject has continued to receive major attention. Differences in the dyeing behavior of Perlon L and nylon have been ascribed to differences between the thermal constants of the two fibers [1600]. Ender [1588] has also considered the characteristic dyeing behavior of nylon and Perlon. The afterchrome method of dyeing nylon, the surface dyeing of nylon, the dyeing of nylon in mixtures with other fibers, and special problems associated with hosiery dyeing have also been discussed [1585, 1610, 1614, 1620, 1621]. Koch [1608], in particular, has presented a rather broad discussion of the preparation, pretreatment, dyeing, and finishing of hosiery, dealing mainly with 15-den. nylon hose. The dyeing of caprone hosiery with direct dyes [1551] and the dyeing of Algosols on cotton and rayon hosiery [1572] have been discussed.

Dispersed acetate and vat colors are recommended for dyeing Orlon acrylic fiber [1553]. The acetate dyes are particularly valuable for obtaining pastel to medium shades in jig and beck equipment. Insoluble vat dyes applied to Orlon under pressure at 250°F give fast shades suitable for outdoor uses. Orlon does not show affinity for acid dyes, however, and is

therefore useful as a white effect thread in worsted piece dyeing with Chromacyl or chrome colors [1556]. Clapham and Gamble [1580] have presented successful dye formulas for Orlon. Carmichael [1574] has discussed the dyeing of polyester fibers with acetate dyes. Woodruff [1650] has reported that Acrilan can be dyed with acid colors at pH 1.2 to 1.4.

Although dynel does not dye readily, it has been possible, through the use of high temperatures, sodium sulfate, anion-active dispersers, paraphenylphenol, and cuprous compounds, to apply successfully acetate dyes, basic dyes, acid dyes, vat dyes, leuco esters of vat dyes, and pigments [1590]. Other processes for dyeing polyvinyl chloride fibers have been reported [1554, 1606]. Caroselli [1575] has contributed information on the dyeing, printing, and finishing of decorative glass fabrics. Modern processes used in the dyeing, printing, and finishing of viscose rayon have been discussed, including boiling-off, pad-dyeing, festoon drying, and printing [1573]. Henderson [1602] has proposed that unevenness which occurs in the dyeing of irregular viscose yarn can be avoided by careful selection of dyes that diffuse rapidly into the fiber, and by careful control of dyeing conditions. Himmelreich [1603] has related uneven dyeing in rayon to uneven tensions during manufacturing. Other papers on the dyeing of viscose rayon have been presented [1561, 1563, 1565, 1653]. Hampson [1596] and Belloni [1560] have outlined the use of vat dye pigments in the dyeing of viscose rayon cakes. York [1651] has pointed out that acetate rayon can be dyed economically with dyes which normally have no affinity for that fiber through the use of cyclohexylamine. More important practical methods for dyeing cellulose acetate, with the advantages and drawbacks of each method, have been discussed by Wojatschek [1648]. Bräuer [1569] has presented methods for obtaining the highest all-round colorfastness on acetate rayon, particularly for dyeing effect yarns where cost may be secondary to fastness. Jentgen [1605] and Kanter [1607] have discussed spun-dyed rayon. Marsden and Urquhart [1617] have published a comprehensive study of technical processes for delustering acetate rayon.

5. Printing.—Habel [1665] has reviewed the developments in textile printing in the past 50 years, and has given particular attention to the possibilities for future improvements.

The technical aspects and advantages of screen printing have been presented [1655, 1664], and Schmidt [1668] has discussed modern cylinder printing. Methods of hand printing [1661] and batik work [1660] have also been described. Bartl [1659] and Hausermann [1666] have given some new information on pigment printing and dyeing. Royle [1667] has outlined the use of resinous-copper complexes in printing, and believes that new aftertreatment techniques on a selected range of direct dyes may cause the replacement of vat dyes when fastness to chlorine is not of paramount importance. Practical problems in the preparation and stabilization of print pastes have been discussed [1656–1658]. Downey [1662] has outlined some faults which may occur during the aging of printed fabrics, and has also dealt with their oxidation and washing-off [1663].

6. Finishing.—

(*a*) General: Eight reviews of textile finishing have been presented in the literature during 1951—some are rather general in nature [1689, 1693, 1703], while others cover more specific aspects of this subject. Whewell and Turner [1734] and Sedgwick [1718] have been concerned with mechanical finishing processes, which are carried out by the application of heat, pressure, or moisture. Colomb [1686] has traced the origin of many defects which occur during dyeing and finishing. Weber and Martina [1731–1733] have reviewed modern finishing processes for synthetic fibers. A number of miscellaneous papers have appeared on such subjects as the heat treatment of nylon fibers [1669, 1691, 1715], carving of fabrics by chemical etching [1700], plisséing of nylon and Perlon fabrics [1709], finishing of pile materials [1708], continuous carbonizing [1719], machinery for finishing woven fabrics [1726], finishing difficulties due to the use of inferior spinning oils [1677], and the use of modified natural-rubber latex for textile finishing [1681].

(*b*) Milling: Most of the literature on milling and finishing of wool during the past year has been of a general nature. Whewell [1313] has paid particular attention, however, to the importance of wool scouring in relation to further mechanical and chemical treatments. Sedgwick has discussed the theory [1717], practice [1716], and results [1720] of different milling processes, and methods for milling low-grade woolens without undue flocking have been presented by Atkinson [1673]. Tiquet [1723] has surveyed the contributions of research methods to

wool processing. Rogers [1710] has described the dry finishing of wool fabrics. LaFleur [1701], in a study of the fulling characteristics of a lightweight woolen fabric, has concluded that although soap is not indispensable for good fulling, it is difficult to find a satisfactory substitute. Von Bergen [1730] has discussed the physics and chemistry of the wet finishing of woolen fabrics. Hall [1696] has described the application of ultrasonic vibrations in the treatment of wool textiles for shrink-resistance.

(*c*) Special Finishes: Several authors have made general surveys of special finishes [1678, 1680, 1685, 1695, 1725]. Nuessle [1705] has discussed the chemical finishing of fabrics and particularly the use of resins on synthetic fibers. Trevor [1724] has summarized the advantages of the use of polyvinyl acetate emulsions in textile finishing, and Horn [1698] has discussed "nylonizing" of nylon fibers.

General principles of fabric finishing have been developed historically and logically by Drukker [1688]. Oesterling [1706] has surveyed the interrelationship of functional fabric properties produced by the use of special textile finishes. The production of crease-resistant finishes through the application of synthetic resins has been treated in a number of papers [1676, 1679, 1692, 1694, 1712], and special attention has been given to producing crease-resistant cotton [1670, 1687, 1713]. A mechanism for the formation of odor in fabrics that have been treated with nitrogen-containing resins has been proposed [1690]. Harding [1697] has reviewed past developments and future prospects in the field of water-repellent textiles. Blumenthal [1682–1684] and others [1672, 1729] have presented articles on the application of various compounds for achieving water-repellency and a measure of resistance to microorganisms. Williams [1735] has discussed other aspects of mildew-resistant fabrics.

The needs of the Armed Forces continue to encourage research on flame-retardants. McQuade [1704] has emphasized strongly the value to the combat soldier of lightweight, fire-resistant clothing. Little [1702] has reviewed the fundamentals of flame retardancy, and Ulrich [1728] has outlined the general methods of securing this property in fabrics and procedures for identifying the finish on treated materials. Various methods for imparting durable fire-retardancy to fabrics have been discussed [1674, 1699, 1714].

The dimensional stabilization of fabrics has received considerable attention. Roy [1711] and Pradon [1707] have presented reviews of the mechanical and chemical processes involved in fabric shrinkage. Data on the mechanism of the stabilization of nylon fabrics and the effect of this process on their physical properties have been given by Bennett [1675]. A discussion of the use of steam setting for stabilizing nylon has also been presented [1671]. Staples [1721] has discussed factors contributing to the shrinkage of rayon fabrics, while Wills [1736] has summarized the physicochemical properties of the cotton fiber which are related to the stabilization of fabrics. Turl [1727] has outlined the factors affecting wool fabric shrinkage, and Stewart [1722] has evaluated four methods of making men's half-hose shrink-resistant with respect to physical and chemical changes and serviceability.

7. Drying.—Thomas [1752] has surveyed past and present trends in textile drying, and Friedman [1744] has also reviewed recent work in this field. A number of papers of interest to the textile industry were presented at a Symposium on Drying sponsored by the Institute of Fuel. These included studies on loose stock, skein, and package drying machinery [1740], the operation of stenters [1737, 1753], cylinder drying [1746], and the drying of packaged wool [1747], viscose staple [1741], and dyed viscose cakes [1738]. Walter [1756–1758], Preston and coworkers [1749, 1750], Mansmann [1748], and Fourné [1742] have discussed various aspects of practical textile drying. Textile heating and drying with high frequencies [1755], infrared radiation [1739, 1754], and molten-metal baths [1745] have been described. Fourt and coworkers [1743] have investigated the rate of drying of fabrics under household conditions, and Satlow [1751] has reported on the drying of linen thread.

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III. Research

A. Chemistry of Cellulose and Starch

1. Cellulose

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7. *Drying*

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